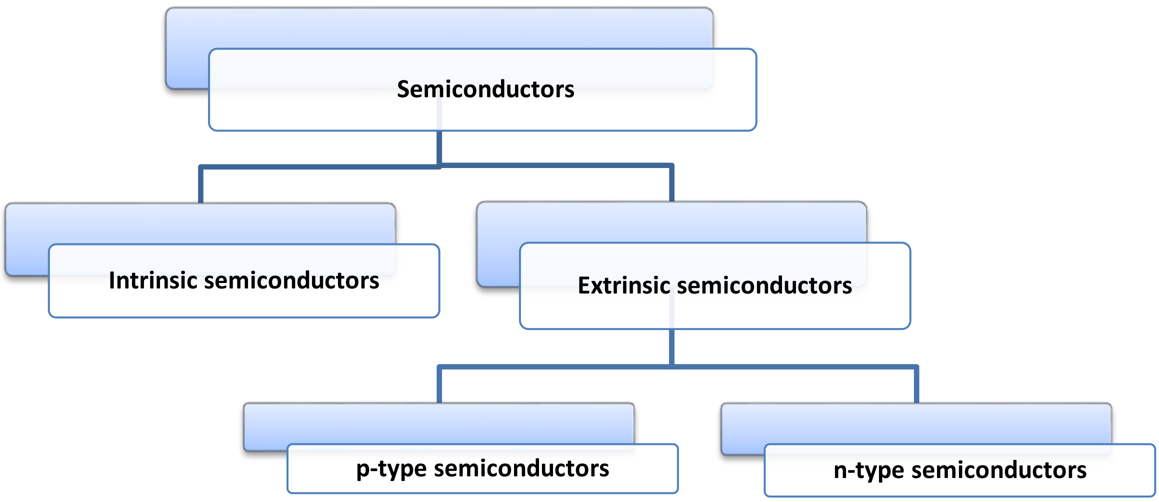
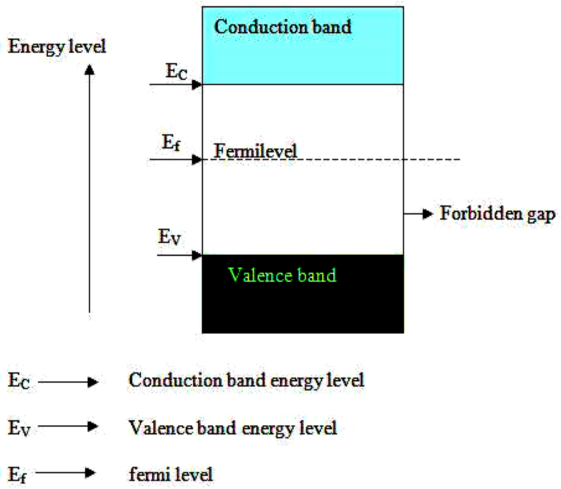
Semiconductors:-

The materials in which energy gap is very small i.e., Eg= 1.1ev or Eg < 3 eV are called semiconductors. These materials electrical conductivity lies between conductors and insulators. In these materials electrons and holes both are responsible for electrical conduction.

Semiconductors mainly classified as follows.



Intrinsic semiconductors:-



A pure semiconductor which is not doped is termed as intrinsic semiconductor. In Si crystal, the four valence electrons of each Si atom are shared by the four surrounding Si atoms. An electron which may break away from the bond leaves deficiency of one electron in the bond. The vacancy created in a bond due to the departure of an electron is called a hole. The vacancy may get filled by an electron from the neighboring bond, but the hole then shifts to the neighboring bond which in turn may get filled by electron from another bond to whose place the hole shifts, and so on thus in effect the hole also undergoes displacement inside a crystal. Since the hole is associated with deficiency of one electron, it is equivalent for a positive charge of unit magnitude. Hence in a semiconductor, both the electron and the hole act as charge carriers.

In an intrinsic semiconductor, for every electron freed from the bond, there will be one hole created. It means that, the no: of conduction electrons is equal to the no: of holes at any given temperature. Therefore there is no predominance of one over the other to be particularly designated as charge carriers.
A broken covalent bond creates an electron that is raised in energy, so as to occupy the conduction bond, leaving a hole in the valence bond. Both electrons and holes contribute to overall conduction process.

In an intrinsic semiconductor, electrons and holes are equal in numbers. Thus $n = p = n_i$.

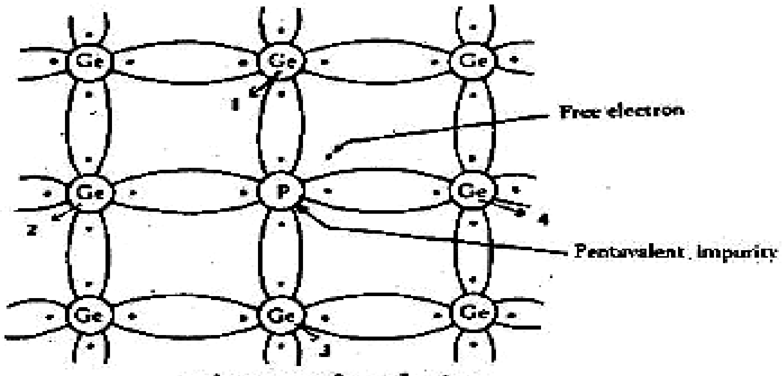
The Fermi energy level for intrinsic semiconductor is lies at the middile of the enengy gap.

EXTRINSIC SEMICONDUCTORS :-

Intrinsic Semiconductors are rarely used in semiconductor devices as their conductivity is not sufficiently high. The electrical conductivity is extremely sensitive to certain types of impurity. It is the ability to modify electrical characteristics of the material by adding chosen impurities that make extrinsic semiconductors important and interesting.

Addition of appropriate quantities of chosen impurities is called doping, usually, only minute quantities of dopants (1 part in 10^3 to 10^{10}) are required. Extrinsic or doped semiconductors are classified into two main types according to the type of charge carries that predominate. They are the n-type and the p-type.

N-TYPE SEMICONDUCTORS:

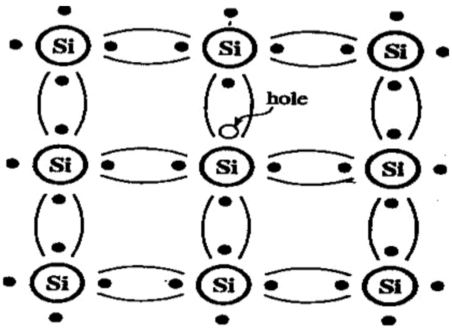


n–type semiconductor

Doping with a pentavalent impurity like phosphorous, arsenic or antimony the semiconductor becomes rich in conduction electrons. It is called n-type the bond structure of an n-type semiconductor is shown in Fig.

Even at room temperature, nearby all impurity atoms lose an electron into the conduction band by thermal ionization. The additional electrons contribute to the conductivity in the same way as those excited thermally from the valence bond. The essential difference between the two mechanisms is that ionized impurities remain fixed and no holes are produced. Since pentavalent impurities donate extra carrier electrons, they are called donors.

P-TYPE SEMICONDUCTORS:-



FORMATION OF HOLE DUE TO DOPING

They are produced by doping an intrinsic semiconductor with trivalent impurities (e.g. boron, aluminum, gallium, or indium). These dopants have three valence electrons in their outer shell. Each impurity is short of one electron for covalent bonding. The vacancy thus created is bound to the atom at 0 K. It is not a hole. But at some higher temperature an electron from a neighbouring atom can fill the vacancy leaving a hole in the valence bond for conduction. It behaves as a positively charge particle of effective mass m_h*. The bond structure of a p-type semiconductor is shown in Fig.

Dopants of the trivalent type are called acceptors, since they accept electrons to create holes above the top of the valence bond. The acceptor energy level is small compared with thermal energy of an electron at room temperature. As such nearly all acceptor levels are occupied and each acceptor atom creates a hole in the valence bond.

In extrinsic semiconductors, there are two types of charge carries. In n-type, electrons are more than holes. Hence electrons are majority carriers and holes are minority carries. Holes are majority carries in p-type semiconductors; electrons are minority carriers.

Direct and indirect band gap semiconductors:-

In a **direct band gap semiconductor**, minimum-energy state in the conduction band (CB -minima) and the maximum-energy state in the valence band (VB-maxima) occur at the same value of momentum (k) in the Brillouin zone.

Best example of direct band gap semiconductors are GaAs, InAs, InSb, CdSe, ZnS

In case of direct band semiconductor electron in conduction band (CB) minima , recombine directly with the holes in valence band (VB) maxima without change in momentum (k-value) as well as kinetic energy, so energy will be emitted in the form of light (Photon) , this phenomenon is called as "SPONTANEOUS EMISSION"

Relative carrier life time of charge carriers is small in case of direct band gap semiconductor

If the k-vectors (Propagation constant or wave vector) are the different for minimum-energy state in the conduction band (CB -minima) and the maximum-energy state in the valence band (VB-maxima) then, it is called a "**Indirect band gap semiconductor**". Best examples of indirect band gap semiconductors are Si and Ge.

In case of indirect band gap semiconductors during excitation there is change in momentum, K.E. as well as direction and path of electron. In this semiconductors energy emits in the form of heat (Phonon).

Carrier life time in case of indirect band gap semiconductor is greater than the carrier life time of direct band gap semiconductor

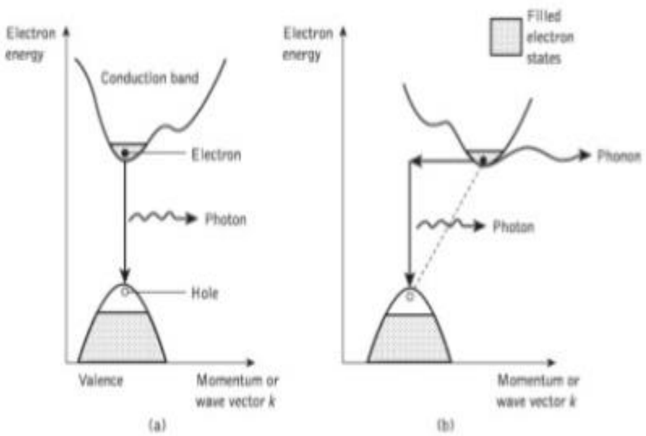


Fig. Energy-momentum (E-k) diagrams of (a) direct band gap semiconductor, (b) indirect band gap semiconductor

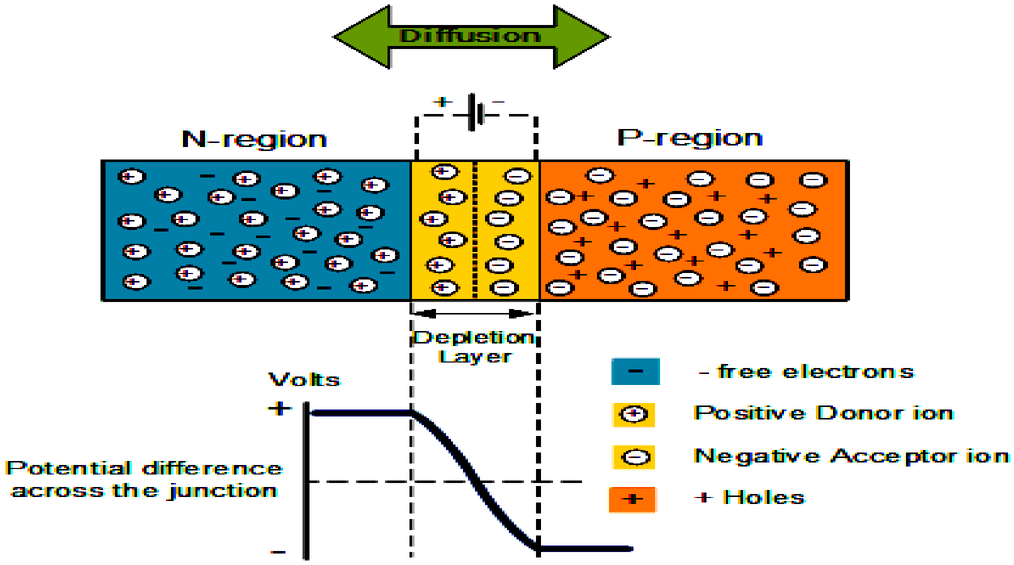
Difference between direct band gap semiconductor and indirect band gap semiconductors:-

Direct band gap semiconductor	**Indirect band gap semiconductor**
minimum-energy of conduction band and maximum-energy of valence band have same k-value	minimum-energy of conduction band and maximum-energy of valence band have different k-values
In this semiconductors energy emits in the form of light (Photon).	In this semiconductors energy emits in the form of heat (Phonon).
Life-time of charge carriers is very less	Life-time of charge carriers is more

Examples: GaAs, InAs, InSb, CdSe, ZnS	Examples: Si, Ge

Formation of P-N Junction diode:-

Junction diode is formed by placing of P type crystal in contact with n-type crystal and subjecting to high pressure so that it becomes a single piece. The surface of contact of P and N-type crystals is called junction. A P-N Junction is shown in fig. The P type region has (positive) holes as majority carriers. Similarly N-type region has (negative) electrons as majority charge carriers.



In addition to these majority carriers, there are few minority charge carriers in each region. The P-region contains a few electrons while the n region contains a few holes. So holes diffuses from P –side to n-side and electrons from n side to p side.

Holes leaving and electrons entering the P-side make it negative. Similarly holes entering and electrons leaving the n-region make it positive. Thus, there is net negative charge on the p side of the junction and net positive charge on n-side. This produces an electric field across the junction. Equilibrium is established when the field becomes large enough to stop further diffusion of the majority charge carriers. The field helps the minority carries to move across the junction.

The region on either side of the junction which becomes depleted (free) of the mobile charge carries is called the depletion region. The thickness of this region is of the order of 10^{-6}m. The potential difference across the depletion region is called the potential barriers.

Energy diagram of PN diode:

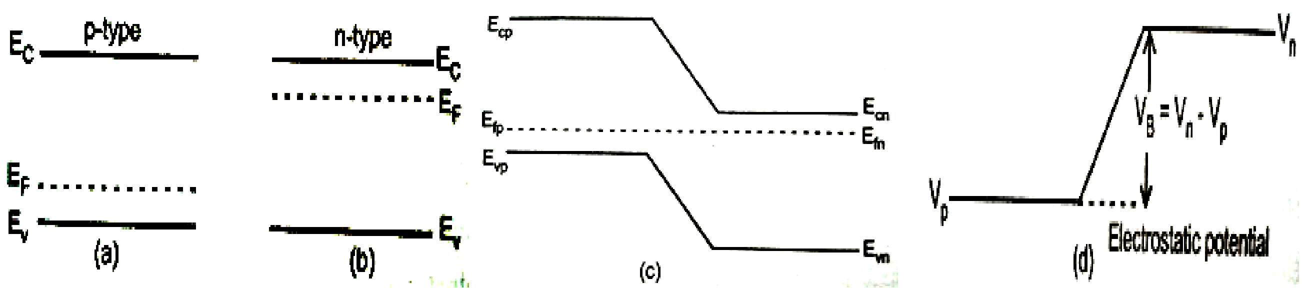
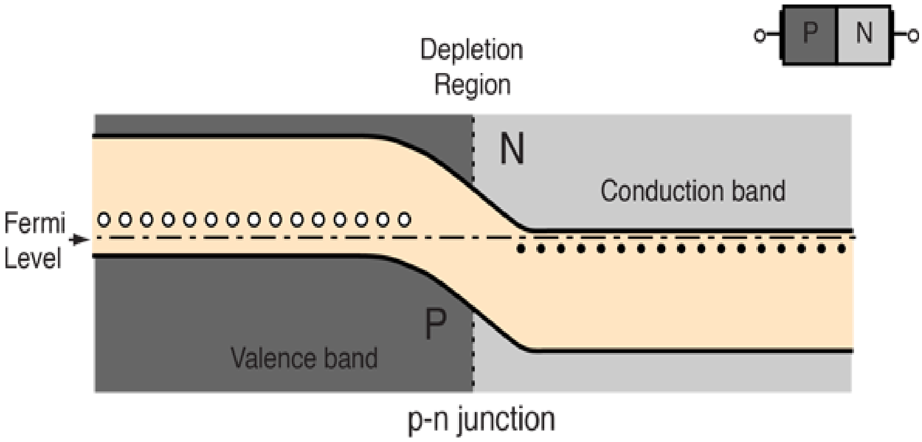
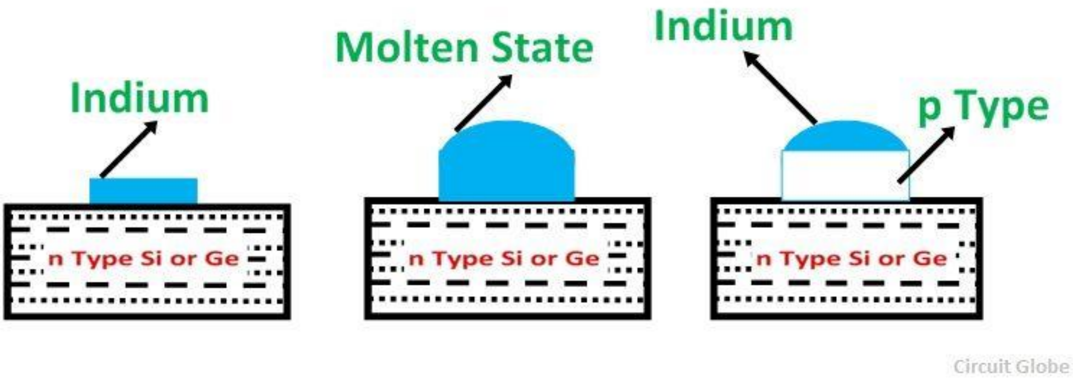


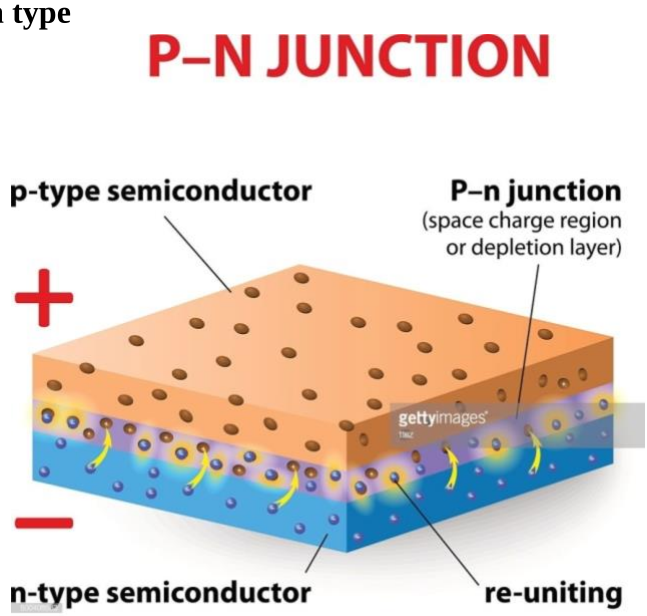
Fig: (a) and (b) Energy level diagram of p-type and n-type semiconductors respectively (c)Energyleveldiagramof PN junction and (d) formation of potential barrier across the junction



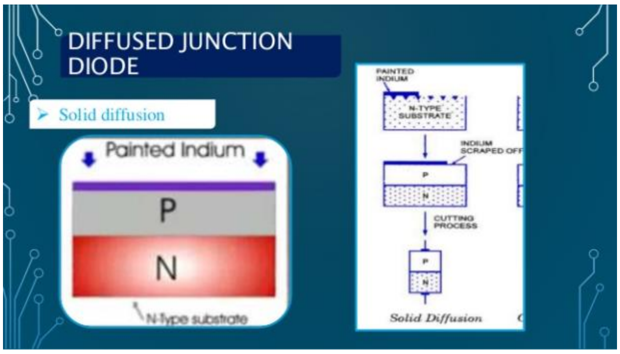
Fabrication of PN Junction Diode
Growth Junction



Fused Junction type

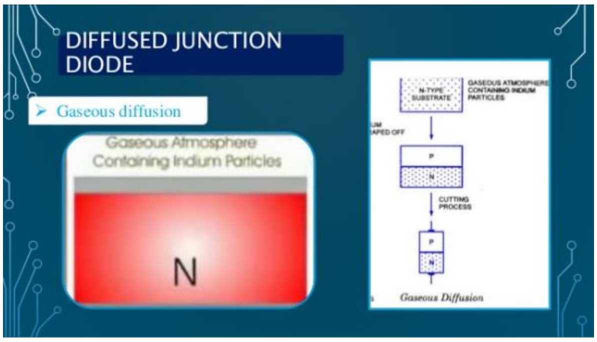


Diffusion Type
Solid Diffusion Type
Dopant of other kind painted on an Extrinsic semiconductor.



Gas Diffusion Type

A semiconductor heated in the presence of vapours of other kind of dopant.



V-I Characteristics of a junction diode:

Graphs drawn between bias voltage and circuit current of a junction diode are called characteristics of the diode.

1. Forward Bias:-

This is obtained by plotting a graph between forward bias voltage and circuit current. The forward voltage is gradually increased in steps and corresponding current readings are noted. A graph is then plotted between voltage and current.

Practically no current flows until the barrier voltage is overcome. Once the external voltage exceeds the barrier voltage, the current increases rapidly, approximately exponentially.

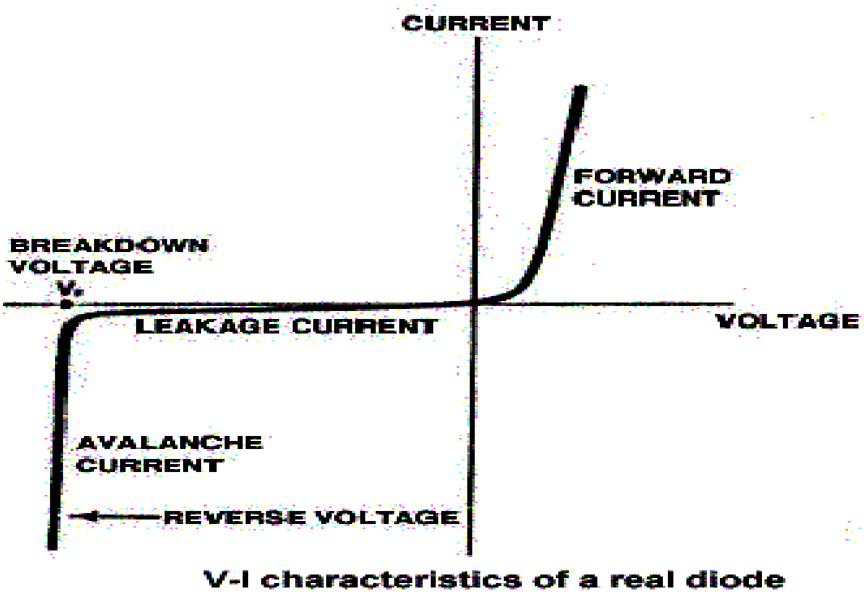


Fig: V-I Characteristics of a PN junction

2. Reverse Bias:-

The reverse voltage is gradually increased in steps and corresponding readings are noted. A graph is ploted between voltage and current. With reverse bias the reverse current remains very small over a long range, increasing very slightly with increasing bias.

If the reverse bias is made very high, the covalent bonds near the junction breakdown and a large number of electron hole pairs are liberated,the reverse current then increases abruptly to a large value. This is known as ‘Avalanche breakdown’ and may damage the junction by excessive heat generated unless the current is limited by external circuit. This phenomenon is used in making zener diodes.

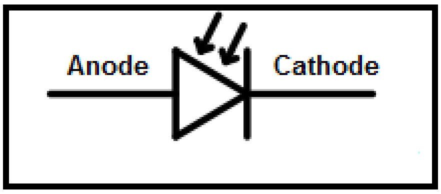
The maximum voltage that a junction diode can bear without breakdown is called zener voltage or reverse breakdown voltage.

Effect of temperature according to diode equation, I = Io $\left(e^{\frac{ev}{\eta kt}} - 1 \right)$

circuit current increases with increase of temperature for 10^{O}c raise of temperature the current nearly doubles for Ge and Si.

Photo diode:

A **photodiode** is a semiconductor p-n junction device that converts light into an electrical current. The current is generated when photons are absorbed in the photodiode.

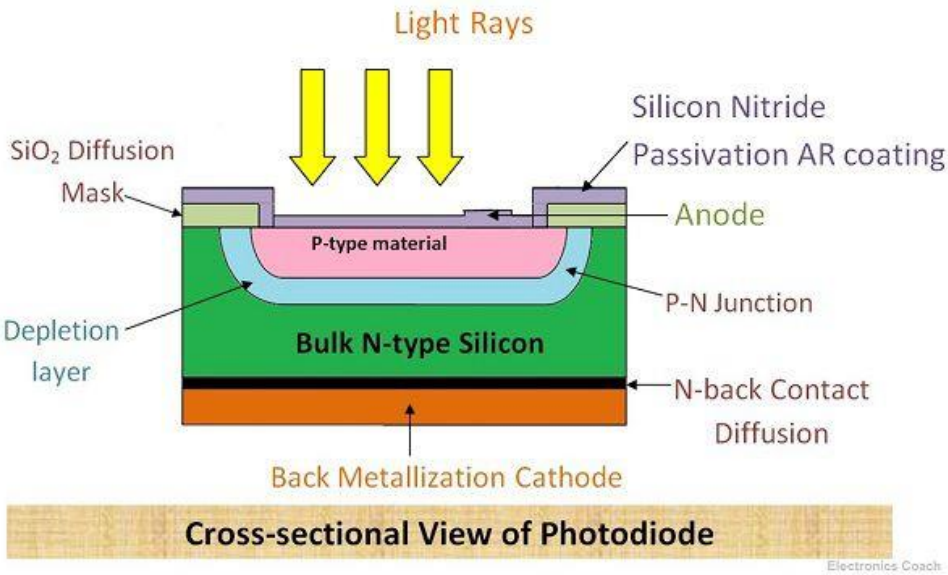


Symbol of Photo diode

The function of the photo diode junction is the opposite an LED function. In an LED, photons are released in response to the current flow through the junction. In a photo diode, the photons are absorbed resulting in the generation of the carriers that manifest as current through the junction.

Many diodes designed for use specially as a photodiode use a PIN junction rather than a p–n junction, to increase the speed of response.

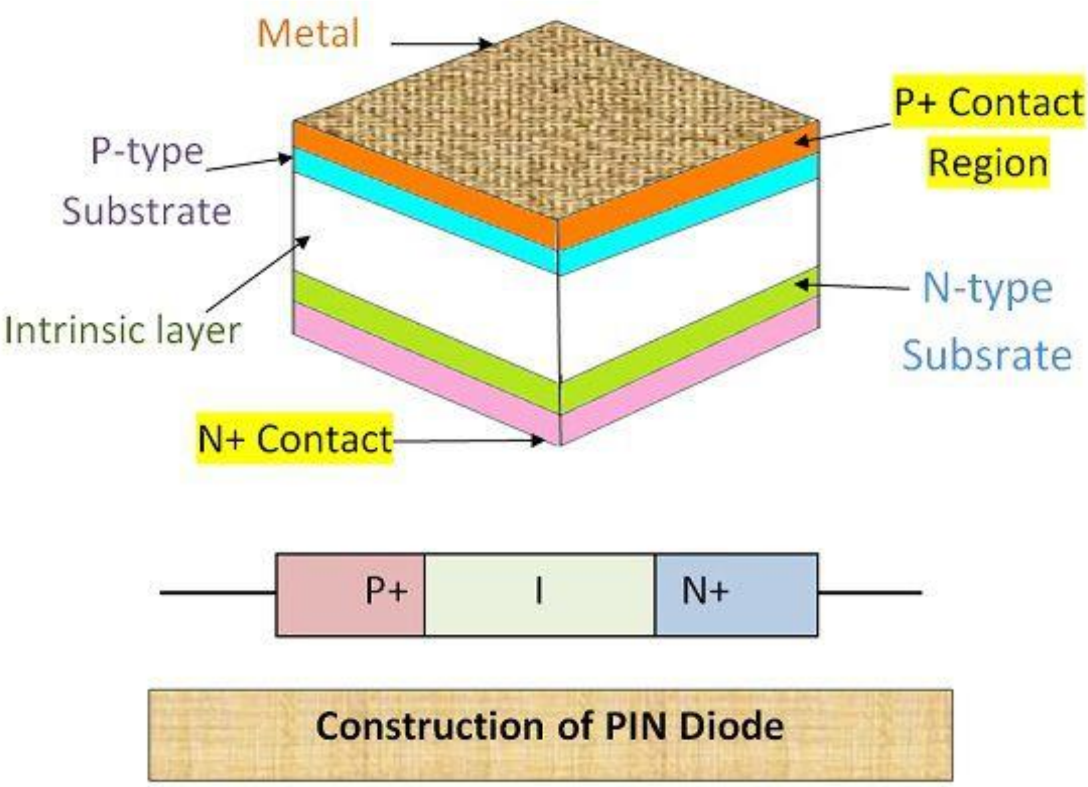
When a photon of sufficient energy strikes the diode, it creates an electron–hole pair. If the absorption occurs in the junction's depletion region, these carriers are swept from the junction by the built-in electric field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced.



Cross-sectional View of Photodiode

CONSTRUCTION:

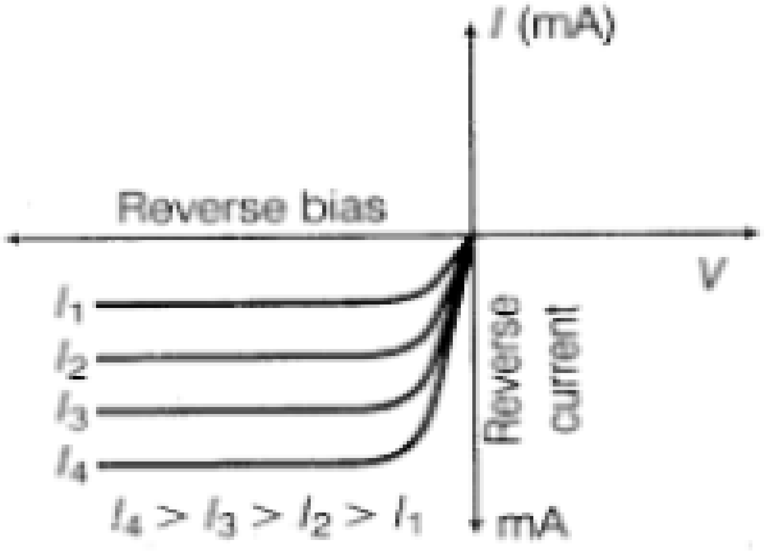
CONSTRUCTION OF PIN DIODE:



Construction of PIN Diode

V-I characteristics of photodiode :

The characteristics of the photodiode are shown clearly in the following figure. A photodiode is operated in a reverse bias mode. Photocurrent is nearly independent of reverse bias voltage which is applied. For zero luminance, the photocurrent is almost zero as shown in the figure.



Modes of Operation of Photodiode

Photo-Conductive:

When the Photo diode operates in reverse biased mode it is called Photoconductive mode. In this, the current flowing in diode varies linearly with the intensity of light incident on it. In order to turn-off the diode, it should be provided with forward voltage.

Photo-Voltaic:

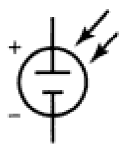
When the diode is operated without reverse biased it is said to be operated in photovoltaic mode. When the reverse biased is removed, the charge carriers are swept across the junction. The barrier potential is negative on N-side and positive on P-side.

Applications

- Photodiodes are used in safety electronics such as fire and smoke detectors.
- Photodiodes are used in numerous medical applications. They are used in instruments that analyze samples, detectors for computed tomography and also used in blood gas monitors, pulse oximeters.
- Photodiodes are used in solar cell panels.
- Photodiodes are used in consumer electronics devices such as compact disc players, remote control devices, exposure meters in camera, photo sensors

<u>SOLAR CELL:</u>

- A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect
  Is known as **solar cell or photo voltaic device.**



Symbol of solar cell

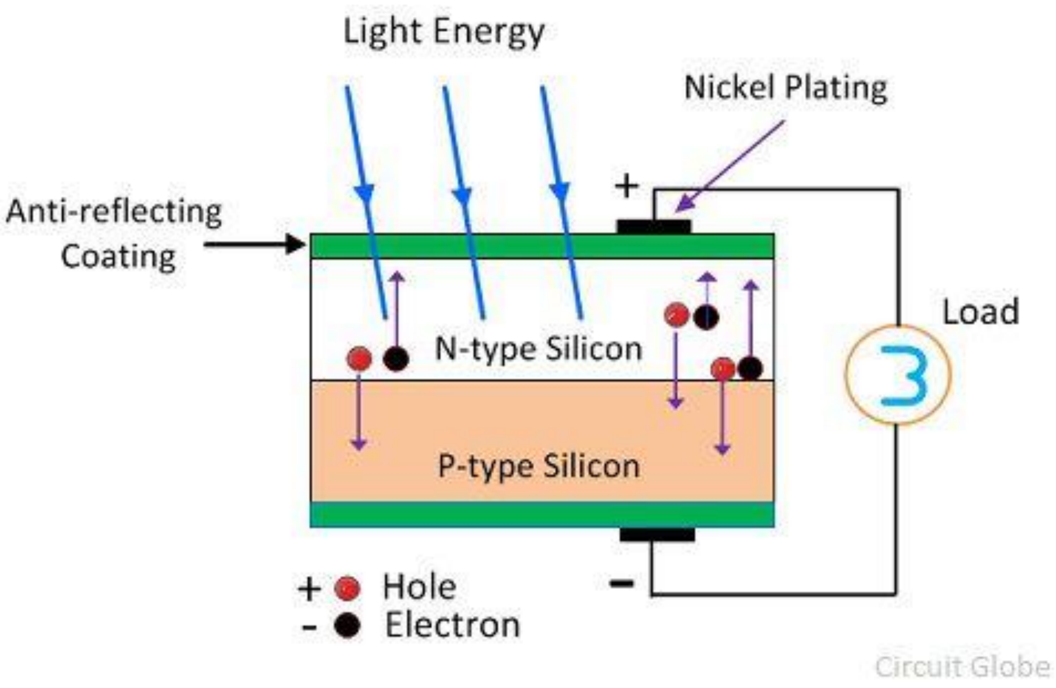
Materials:

Main considerations while selecting a material for solar cell fabrication:

- Band gap (1 to 2eV)
  Semiconductors commonly used for making solar cells are
  Si(1.1eV), GaAs(1.43eV), CdTe(1.45eV).
- High optical absorption.
- Electrical Conductivity.

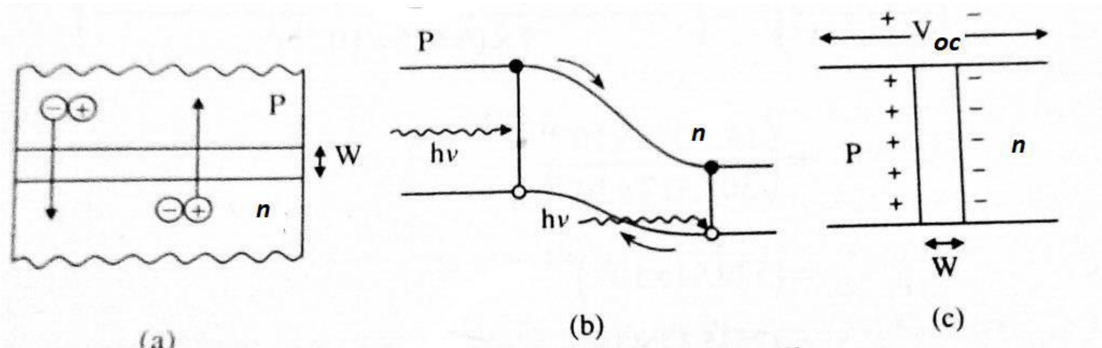
Construction:

- A simple solar cell consist of a p-n junction diode having large junction surface to absorb large radiation.
- In this p-n junction diode n-region ($0.3x10^{-6}$m) is very thin and p-region ($100x10^{-6}$m) is thick.
- In the solar cell the thin region is called the emitter and the other base, light incident on the emitter.
- *N*i plated contacts are connected through a load resistance.



Working:

- **Photon in sunlight fall on the solar panel and are absorbed by semiconducting materials, such as silicon.**
- **Electron are knocked loose from their atoms, causing an electric potential difference. Current starts flowing through the material to cancel the potential and this electricity is captured. Due to the special composition of solar cells, the electrons are only allowed to move in a single direction.**
- **The most commonly known solar cell is configured as a large-area [p–n junction] made from silicon.**
- **Other possible solar cell types are organic solar cells, dye sensitized solar cells, perovskite solar cells, quantum dot solar cells**



Working of a solar cell

Three steps are involved in working of a solar cell, when light falls on it.

1. Generation of charge carriers (electron-hole pair):

When light energy falls on a p-n junction diode, photon collide with valence electrons and impart them sufficient energy enabling them to leave their parent atoms. Thus, electron – hole pairs are generated in both **p** and **n** sides of the junction.

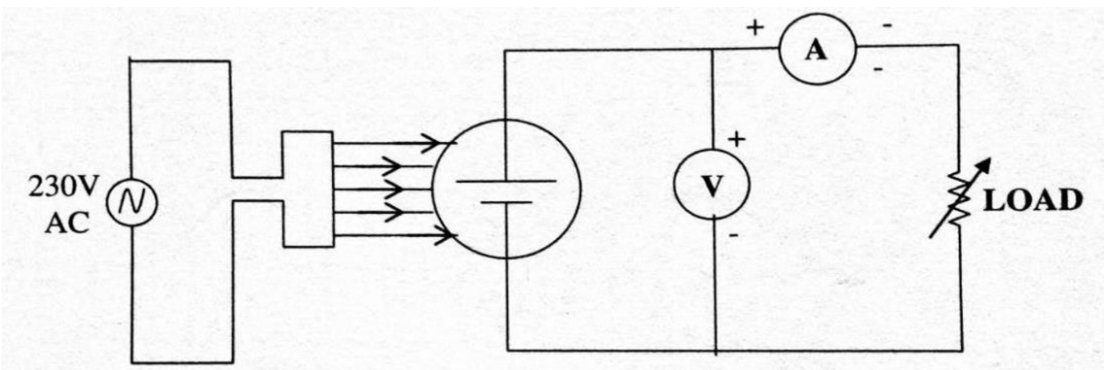
2. Separation of charge carriers:

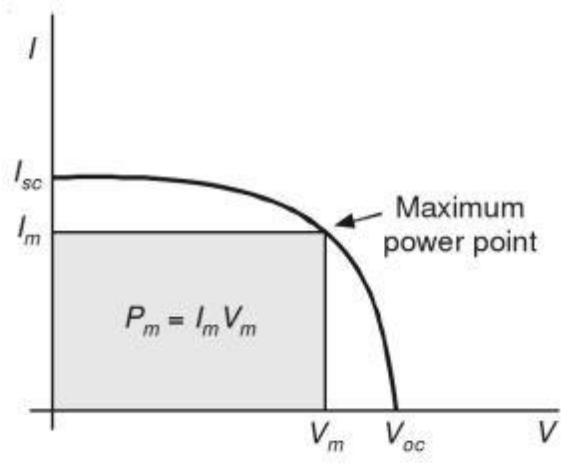
The electron from p-region diffuse through the junction to a n-region and holes from n-region diffuse through the junction to the p-region due to electric field of depletion layer. Thus, hole and electrons are separated out. The accumulation of electron and holes on the two sides of the junction gives rise to open circuit voltage(Voc).

3. Collection of charge carriers:

The flow of electrons and holes constitutes the minority current. The d.c is collected by the metal electrodes and flows through the external load (RL). The d.c is directly proportional to the illumination and also depends on the surface are being exposed to light.

I – V Characteristics:





An *I-V* characteristic of a solar cell with the maximum power point.

The I – V characteristics of solar cell can be determined by connecting load resistance across the voltmeter in series with ammeter. By keeping the light intensity constant we will vary the load resistance in a sequential manner to observe corresponding voltmeter and ammeter reading. A graph is plotted by taking voltage and current along Xand Y axis with the given scale. An exponential curve decay in power is obtained. The curve passes through three significant points.

A. Short circuit current(I_{SC}): It occurs on a point of the curve where the voltage is zero. At this point the power output of the solar cell is zero.

B. **Open circuit voltage (V_O):** It occurs on a point of the curve where the current is zero. At this point the power output of the solar cell is zero. The product of above two quantities(I_{SC} x V_O) gives the **ideal power** of the cell.

C. **Maximum Power ($P_{max)}$:** The cell delivers the maximum power, where the product $I_m V_m$ is maximum. The position of the maximum power is the area of the largest rectangle that can be formed in the V – I curve.

Solar Cell Efficiency:

The efficiency is the most commonly used parameter to represent the performance of a solar cell

Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. The efficiency of solar cell depends upon climate and latitude

- Factors affecting a solar cell's efficiency
- Reflectance
- Thermodynamic efficiency
- Charge carrier separation efficiency
- Charge carrier collection efficiency
- Conduction efficiency.

solar cells are used in solar panels, power calculators, watches, irrigation systems,

Solar cells are also used extensively in satellites and space vehicles as most important long duration power supply.

Advantages of solar power

- The very first benefit of using this technology is that solar energy is renewable.
- This is a 100%environment-friendly.
- Contrary to fossil fuels, this technology is not going to release any greenhouse gases, harmful agents, volatile material or carbon dioxide into the environment.
- Solar panels are highly durable and reliable.
- These systems don’t have any moving systems and hence they don’t require any replacement.

Applications

- Rural electrification: The provision of electricity to rural areas like power supply to remote houses, electrification of the health care facilities, irrigation and water supply and treatment.
- Ocean navigation aids: Many lighthouses are now powered by solar cells.
- Telecommunication systems: radio transceivers on mountain tops are often solar powered.
- Solar Power Satellite.
- Solar cars.
- Solar Lighting.
- Solar Thermal Electric Power Plants.

Light Emitting Diode (LED):

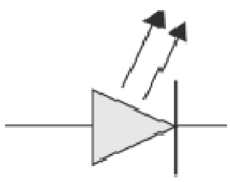
LED is a p–n junction device which emits light when forward biased, by a phenomenon called electro luminescence in the in the UV, Visible or IR regions of the electromagnetic spectrum. The quanta of light energy released are approximately proportional to the band gap of the semiconductors.

LED is PN junction diode.

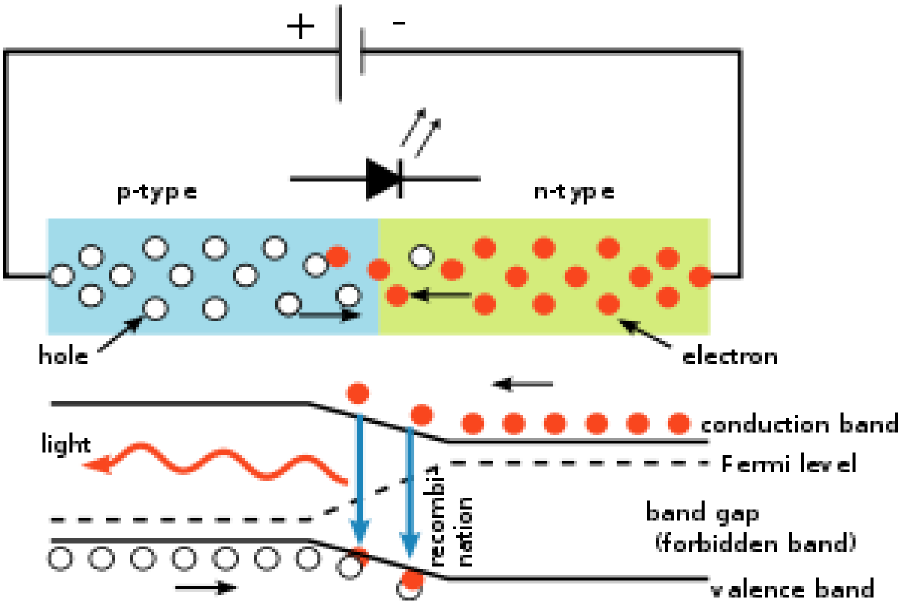
Made of direct band gap material.

Under forward biased condition, minority carrier injection takes place.

Undergo Radiative recombination.

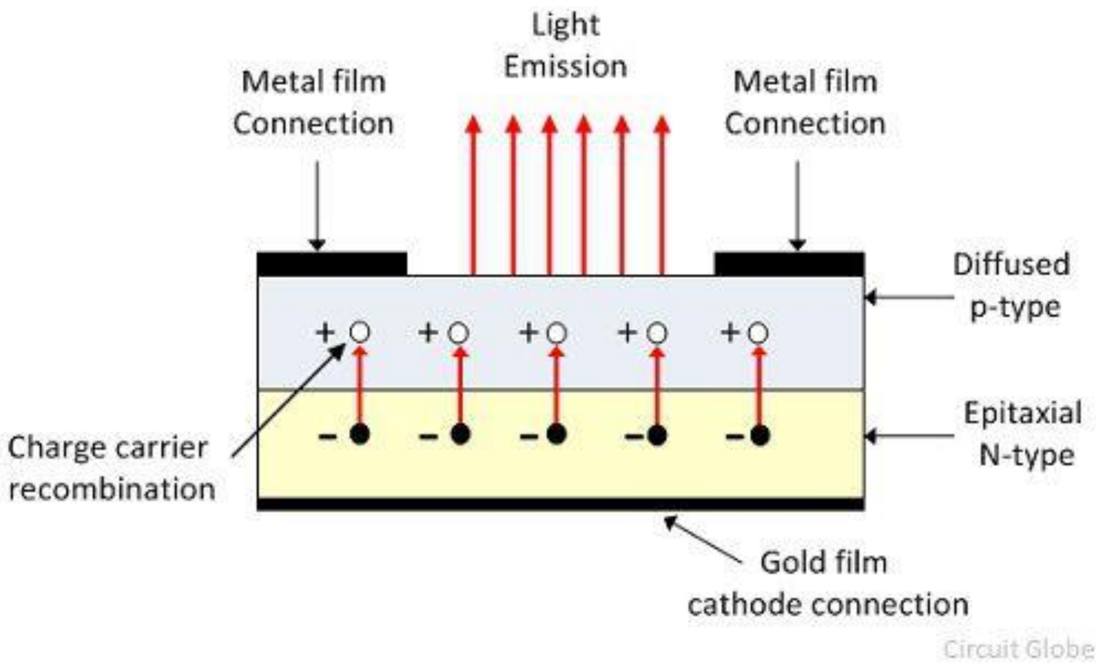


Symbol of LED



Principle & Working:

CONSTRUCTION

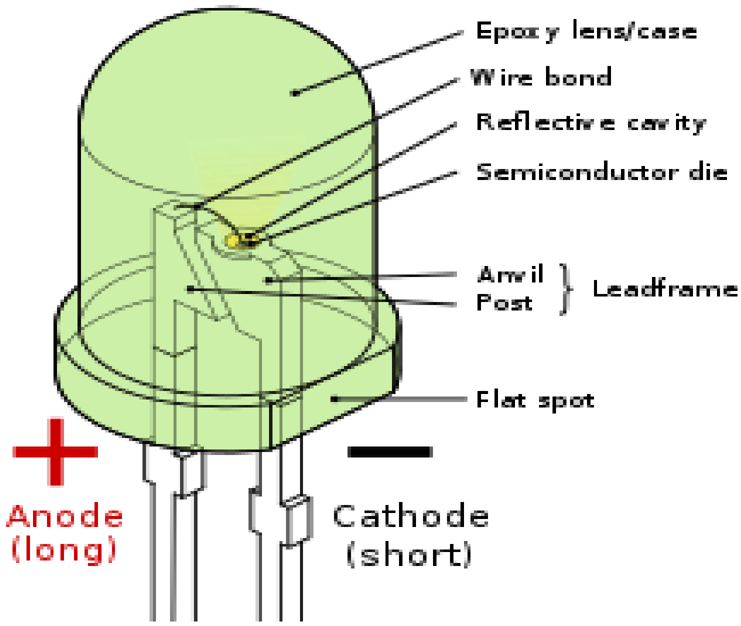


N-Substrate of Gallium Phospate.

Growth of epitaxial P region-Substrate to form PN junction.

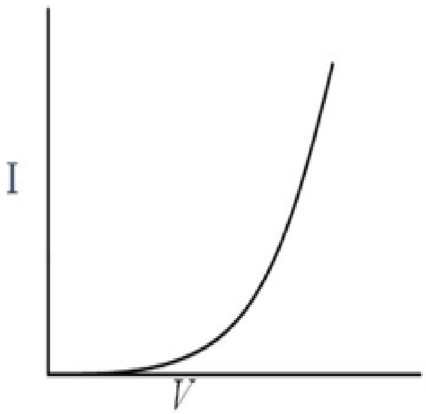
Electrical contacts.

Reflective layer at the bottom.



Top surface dome shaped and transparent.

V-I Characteristics



When a voltage is applied across a p-n junction(Forward biased),the electron crosses p-n junction from the n – type semiconducting material to p – type semiconductor material. These free electrons stay in conduction
band(higher energy state) for a few seconds and while holes present in the valence band. The electron make downward transition from conduction band , recombine with the majority holes in the valence band (spontaneous emission) . During the recombination, the difference in the energy is given up in the form of light radiation. i.e. photon. The energy of light radiation depends on the strength of the recombination. The emitted light is very small in intensity and is of the order of microampere range. Similar, action takes place in n-region also. Under reverse bias no photons emitted.

The wavelength of emitted photon is

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

Where, $h = plancks\ constant\ (6.625 \times 10^{-34}\ JS)$

$$\lambda = \frac{hc}{E_g} = \frac{6.625 \times 10^{-34} \times 3 \times 10^{8} \times 10^{10}}{1.602 \times 10^{-19} E_g} = \frac{12400}{E_g} A^{\circ}$$

Where, Eg is the energy gap in electron volt.

Therefore, colour of the emitted light depends on the type of material used.

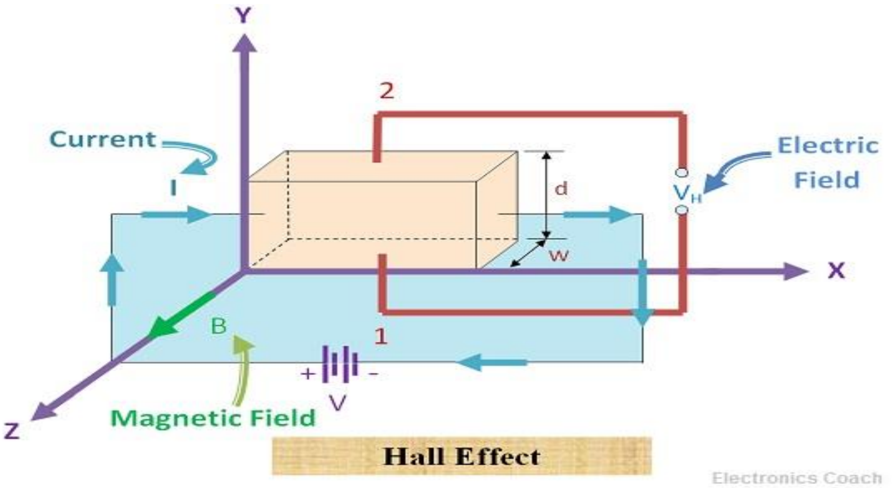
Advantages of LEDs in electronic Display

1) Output is bright and the intensity can be controlled easily by varying current.
2) They can be operated over a wide range of temperature 0 to 700 C
3) Very fast response time in the order of ns and hence very useful as source for optical Communication.
4) Available in different colors.
5) Very small in size and hence can be closely packed for high density display.
6) As long life (about 105 hours) and high degree reliability.
7) Very rugged and hence suitable for any environment.

HALL EFFECT:

When a magnetic field is applied perpendicular to a current carrying conductor or semiconductor, a voltage (electric field) is developed across the specimen in a direction perpendicular to both the current and magnetic field . This phenomenon is called **Hall Effect** and generated voltage is called as the ‘ Hll voltage’.

Hall Effect finds important applications in studying the electron properties of semi conductor, such as determination of carrier concentration and carrier mobility. It also used to determine whether a semi conductor is n-type, or p- type.



THEORY:

Consider a rectangular slab of an n-type Semiconductor carrying current in the positive x-direction. The magnetic field B is acting in the positive direction as indicated in fig: above. Under the influence of the magnetic field, electrons experience a force F_L given by

$$F_L = - Bev \quad \text{---------------} \ (1)$$

Where e = magnitude of the charge of the electron

v = drift velocity

Applying the Fleming’s Left Hand Rule, it indicates a force F_H acting on the electrons in the negative y-direction and electron are deflected down wards. As a consequence the lower face of the specimen gets negatively charged (due to increases of electrons) and the upper face positively charged (due to loss of electrons). Hence a potential V_H, called the Hall voltage appears between the top and bottom faces of the specimen, which establishes an electric field E_H, called the Hall field across the conductor in negative y-direction. The field E_H exerts an upward force F_H on the electrons. It is given by

$$F_H = - eE_H \quad \text{-------------(2)}$$

F_H acts on electrons in the upward direction. The two opposing forces F_L and F_H establish equilibrium under which

$$F_L = F_H$$

Using eqns (1) and (2)

$$-Bev = -eE_H$$

$$E_H = Bv \quad \text{-------------- (3)}$$

If'd' is the thickness of the Specimen, $E_H = \frac{V}{d}$

$$V_H = E_H\, d = Bvd \quad \text{from eqn (3) ------------------------- 4}$$

If ω is the width of the specimen in z- direction. The current density $J = \frac{I}{wd}$

$$\text{But } J = nev = \rho v \quad \text{-------------------- 5}$$

Where, n = electron concentration , ρ = charge density

$$\rho v = \frac{I}{wd}$$

$$\Rightarrow \ v = \frac{I}{\rho wd} \quad \text{----------------(6)}$$

Substitute equationn(6) in (4), we get

$$V_H = BI / \rho\omega$$

$$\text{(or) } \rho = \frac{BI}{V_H w}$$

Thus, by measuring V_H, I, and ω and by knowing B, the charge density ρ can be determined.

Hall Coefficient:

The Hall field E_H, for a given material depends on the current density J, and the applied field B

i.e., $E_H \propto JB$

$$E_H = R_H\, JB$$

Where R_H is called the Hall Coefficient

Since, $V_H = BI / \rho\omega$

$$E_H = \frac{V_H}{Jwd}$$

Mobility of charge carriers:

The mobility μ is given by $\mu = \frac{v}{E}$

But $J = \sigma E = nev = \rho v$

$$\therefore \sigma E = \rho v$$

$$\text{or} \quad E = \frac{\rho v}{\sigma}$$

$$\Rightarrow \quad \mu = \frac{\sigma}{\rho} = \sigma R_H \quad (\because 1/\rho = R_H)$$

σ is the conductivity of the semi conductor.

Applications of Hall effect:-

a) Determination of the type of Semiconductor: The Hall Coefficient R_H is negative for an n-type Semiconductor and positive for a p-type material. Thus, the sign of the Hall coefficient can be utilized to determine whether a given Semiconductor is n or p type.

b) Determination of Carrier Concentration: Equation relates the Hall Coefficient R_H and charge density is

$R_H = 1/\rho = -1/ne$ (for n-type)
$R_H = 1/\rho = 1/pe$ (for n-type)

Thus, $n = 1/eR_H$

and $P = 1/eR_H$

c) Determination of mobility: According to equation the mobility of charge carriers is given by , $\mu = \sigma|R_H|$
Determination of σ and R_H leads to a value of mobility of charge carriers.

d)Measurement of Magnetic Induction (B):- The Hall Voltage is proportional to the flux density B. As such measurement of V_H can be used to estimate B.

$$B = \frac{V_H d}{I R_H}$$