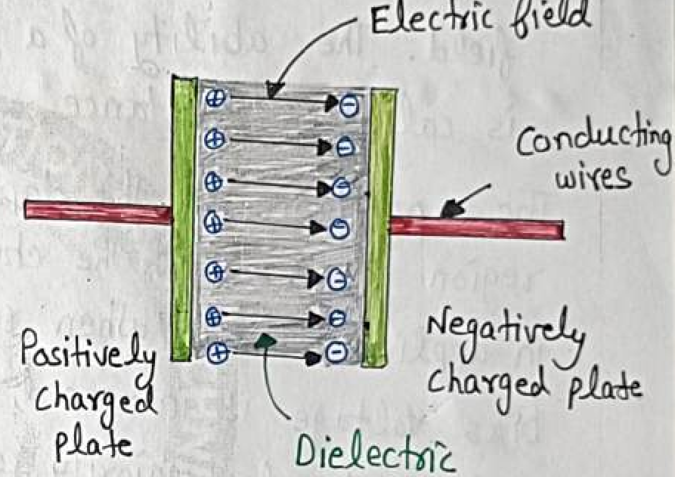
(I) Transition Capacitance [C_T]

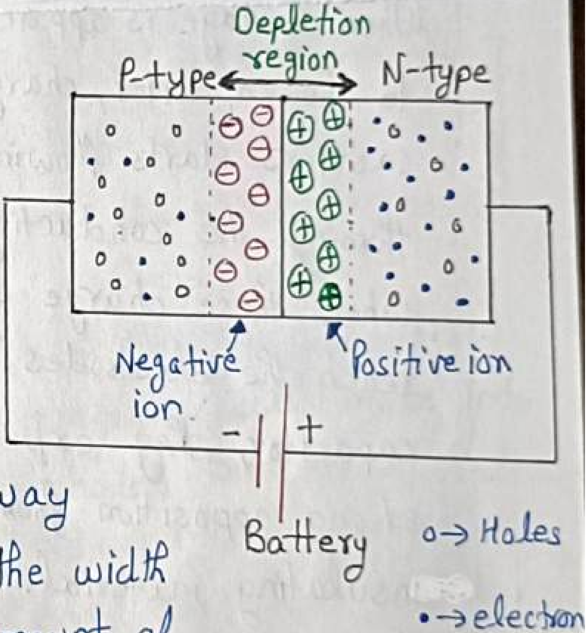
We know that capacitors store electric charge in the form of electric field. This charge storage is done by using two electrically conducting plates separated by an insulating material called dielectric.



When voltage is applied to the capacitor, charge carriers starts flowing through the conducting wire. When these charge carriers reach the electrodes of the capacitor, they experience a strong opposition from the dielectric or insulating material. As a result, a large number of charge carriers are trapped at the electrodes of the capacitor. These charge carriers cannot move between the plates. However, they exerts electric field between the plates. The charge carriers which are trapped near the dielectric material will stores electric charge. The ability of the material to store electric charge is called capacitance.

Similarly, a reverse-biased P-N junction also stores electric charge at the depletion region. The depletion region is made of immobile positive and negative ions.

The P-type and N-type regions act like the electrodes or conducting plates of the capacitor. The depletion region acts like the dielectric or insulating material.



The capacitance at the depletion region changes with the change in applied voltage. When reverse bias voltage is increased, a large number of holes[majority carriers] from p-side and electrons[majority carriers] from n-side are moved away from the p-n junction. As a result, the width of depletion region increases. The amount of capacitance changed with increase in voltage is called transition capacitance, depletion region capacitance, junction capacitance or barrier capacitance.

It can be defined as the change in electric charge per change in voltage i.e.

$$C_T = \frac{dQ}{dV}$$

Also, C_T can be written as

$$C_T = \frac{\varepsilon A}{W}$$

where, ε = Permittivity of the semiconductor
A = area of plates or area of P-type or N-type region

ω = width of depletion region.

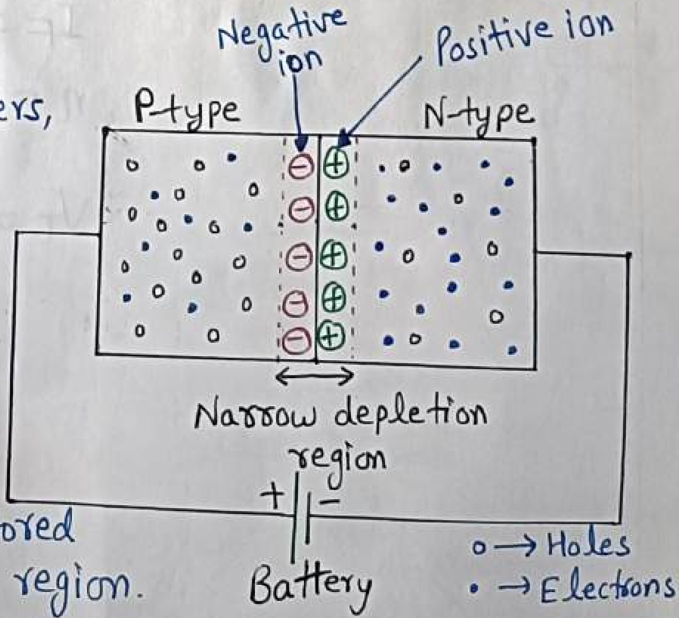
<u>Note</u>:- In forward biased diode, the transition capacitance exist. However, the C_T is very small as compared to the diffusion capacitance. So, it is neglected in forward biased diode.

(II) Diffusion Capacitance (C_D)

It occurs in a forward-biased p-n junction diode. It is also known as storage capacitance. It is denoted as C_D.

The diffusion capacitance occurs due to stored charge of minority electrons and minority holes near the depletion region.

When forward bias voltage is applied to the p-n junction, electrons [majority carriers] in the n-regions will move into the p-region and recombines with the holes. Similarly, holes from the p-region will move into the n-region and recombines with electrons. As a result, width of depletion region decreases.



A large number of charge carriers, which try to move into another region will be accumulated near the depletion region before they recombine with the majority carriers. As a result, a large amount of charge is stored at both sides of the depletion region.

Diffusion capacitance is directly proportional to the electric current or applied voltage. If large electric current flows through the diode, a large amount of charge is accumulated near the depletion region. As a result, large diffusion capacitance occurs.

$$C_D = \frac{dQ}{dV}$$

where C_D = Diffusion capacitance
dQ = change in number of minority carriers stored outside the depletion region
dV = change in voltage applied across the diode.

<u>Range</u> :- in the range of nF (nano farads) to μF [micro farads]

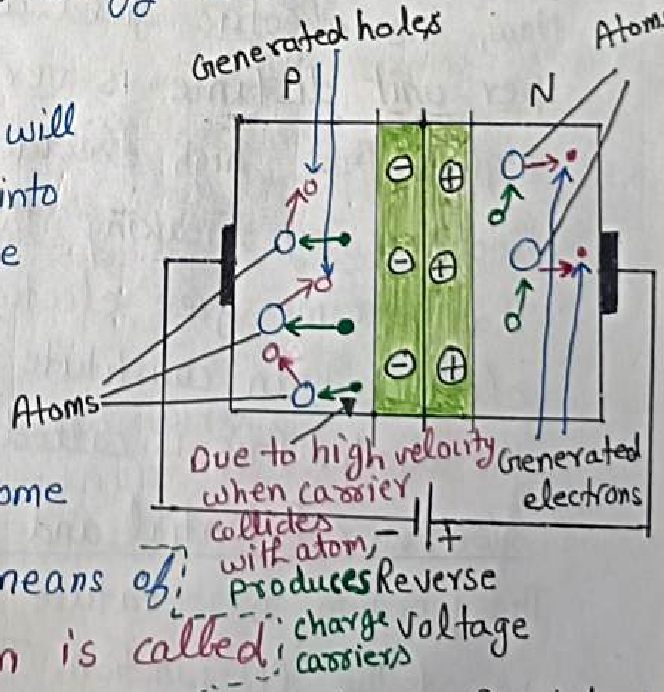
Breakdown in the Reverse Biased Diode

The reverse saturation current depends only on the temperature and it is independent of the reverse voltage applied externally. The breakdown in a reverse biased diode can take place due to the following effects:-

ⓐ Avalanche effect
ⓑ Zener effect.

ⓐ Breakdown due to the Avalanche Effect:-

When a very large reverse voltage is applied to a diode, the velocity of the minority carriers will increase to a great extent. Therefore, the kinetic energy associated with them will also increase. While travelling, these minority carriers will collide with the stationary atoms and impart some of the kinetic energy to the valence electrons present in the covalent bonds.

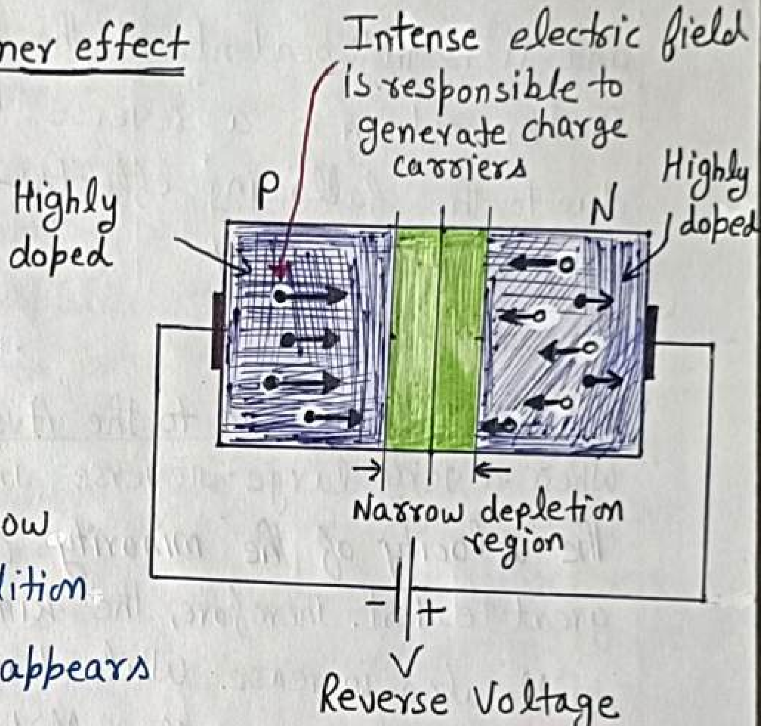


Due to this, these valence electrons will break the covalent bonds and jump into the conduction band to become free for conduction. As, these electrons are moving with high acceleration so they will knock-out some more valence electrons by means of collisions. This chain reaction is called as Avalanche effect. Due to this, in a very short time, a large number of

Avalanche Breakdown.

free minority electrons will be available for conduction and a large reverse current will flow through the reverse biased diode. The avalanche breakdown has thus taken place.

(b) Breakdown due to the Zener effect



The reverse breakdown can take place due to another effect called zener effect.
Due to the heavy doping of P and N-sides of the diodes, the depletion region is narrow in the reverse biased condition and the reverse voltage V appears across the depletion region.
Now, the electric field which is defined as the voltage per unit distance is very intense across the depletion region. This high electric field can pull some of the valence electrons by breaking the covalent bonds. These electrons than become free electrons. A large number of such electrons can constitute a large reverse current through the diode. This is called the breakdown due to zener effect.

Barrier Potential and Temperature

The junction temperature is the temperature inside a diode i.e. at the PN-junction. The ambient temperature is different and it is the temperature of the air outside the diode. When the diode is conducting, the junction temperature is higher than the ambient temperature due to the heat

Zener Diode

A normal P-N junction diode allows electric current only in forward biased condition since it offers only a small resistance to the electric current. Whereas in reverse biased condition, it offers large resistance to the electric current and so blocks large amount of electric current.

If reverse biased voltage applied to the P-N junction diode is highly increased, a sudden rise in current occurs. At this point, a small increase in voltage will rapidly increase the electric current. This sudden rise in electric current causes a junction breakdown called zener or avalanche breakdown. The voltage at which zener breakdown occurs is called zener voltage and the sudden increase in current is called zener current.

A zener diode is a special type of diode designed to operate in the zener breakdown region. It acts like normal P-N junction diode under forward biased condition. Zener diode is heavily doped than the normal P-N junction diode. Hence, it has very thin depletion region. Therefore, it allows more electric current than the normal PN-junction diode.

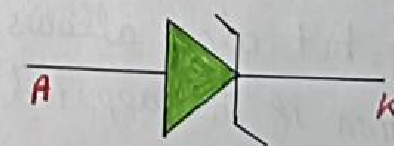
It allows electric current in forward direction like a normal diode but also allows electric current in the reverse direction if the applied reverse voltage is greater than the zener voltage.

Note:- The breakdown voltage of a zener diode is carefully set by controlling the doping level during manufacturing.

Breakdown in Zener Diode :- Avalanche and Zener breakdown

S.No.	Avalanche Breakdown	Zener Breakdown
1:-	The breakdown which occurs because of the collision of the electrons inside the PN-junction is called Avalanche Breakdown.	The breakdown which occurs due to heavy electric field near the PN-junction is called Zener Breakdown.
2:-	The avalanche breakdown occurs in the thick region.	The zener breakdown occurs in the thin region.
3:-	The avalanche breakdown occurs in low doping material	The zener breakdown occurs in heavily doped material.
4:-	This is observed when breakdown voltage V_Z is greater than 6 Volts.	This is observed when breakdown voltage V_Z is below 6 Volts.
5:-	The increase in temperature increases the breakdown voltage.	The increase in temperature decreases the breakdown voltage.
6:-	PN-junction is destroyed after avalanche breakdown.	PN-junction is not destroyed in the zener breakdown.

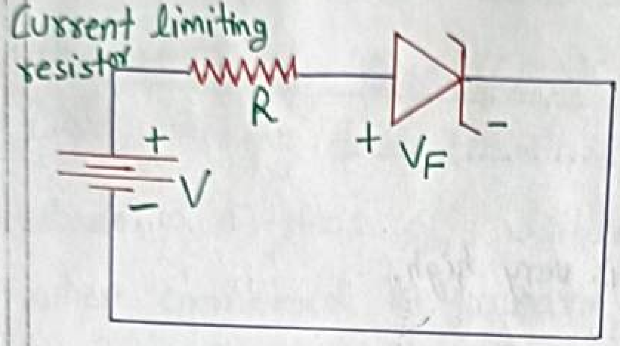
Zener Diode Symbol



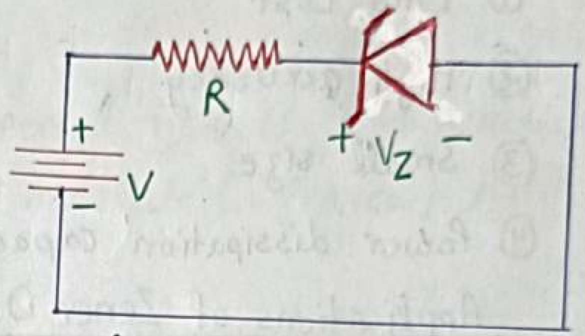
Zener Diode

In zener diode, electric current flows from both anode to cathode and cathode to anode.

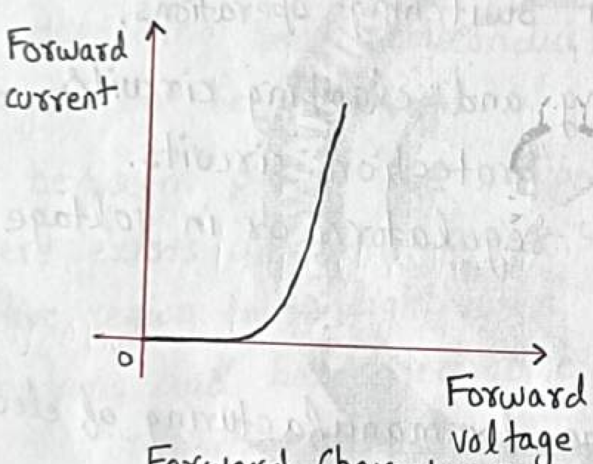
V-I Characteristics of Zener diode



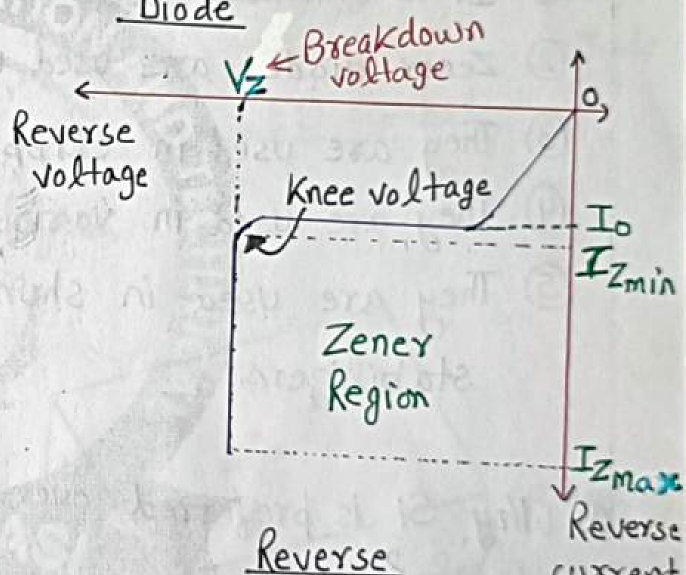
Forward Biasing of Zener Diode



Reverse Biasing of Zener Diode



Forward Characteristics



Reverse Characteristics

When forward biased voltage is applied to the Zener diode, it works like a normal diode.
However, when reverse biased voltage is applied to the Zener diode, it works in different manner. That is, initially it allows a small amount of leakage current to flow until the applied voltage is less than Zener voltage. When reverse bias voltage reaches zener voltage, it starts allowing large amount of electric current to flow. At this point, a small increase in reverse voltage will rapidly increase the electric

current. Due to this sudden rise, breakdown occurs and it is called as zener breakdown.

Advantages of Zener Diode

1. Low cost
2. High accuracy
3. Small size
4. Power dissipation capacity is very high.

Applications of Zener Diode

1. It is normally used as voltage reference.
2. Zener diodes are used in switching operations.
3. They are used in clipping and clamping circuits.
4. They are used in various protection circuits.
5. They are used in shunt regulators or in voltage stabilizers.

Q Why Si is preferred over Ge for manufacturing of electronic devices?

Ans. - Si is preferred over Ge for manufacturing of electronic devices due to following reasons:-

(a) Silicon is available in abundance in nature.

(b) They are less expensive than Germanium.

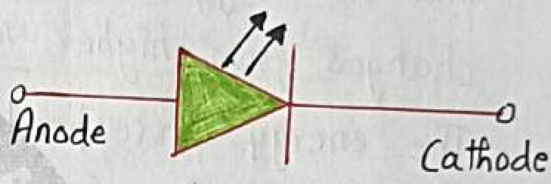
(c) The atomic number of Ge is 32 and for Si it is 14. The number of valence electrons [4] is same for both Si and Ge but the valence electrons for Ge is in 4th shell which means they are farther away from the nucleus, so the force of attraction is less. Due to this they can easily escape and become free. Hence, the Ionization potential of Ge is lesser than that of Silicon.

Chapter 3:- Special Purpose Diodes and their applications

(A) Light Emitting Diode (LED)

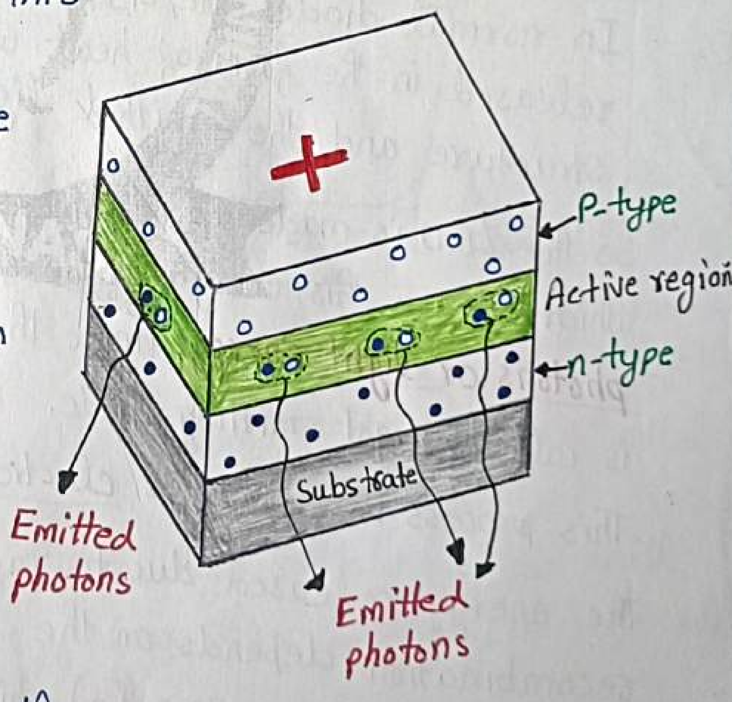
Light emitting diode (LED) is a special type of p-n junction diode that gives off visible or invisible [infrared] light when connected in forward bias.

Construction of LED



LED symbol

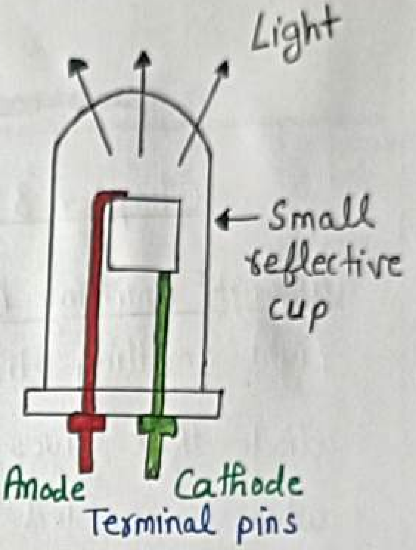
The LED construction comprises of depositing three semiconductor layers on the substrate.
In between p-type and n-type layers, there exists an active region. This active region emits light, when electrons and holes recombine in this region.
Actually when the diode is forward biased, both holes from p-type and electrons from n-type are driven into the active region and as they recombine, the light is emitted.



Construction of LED

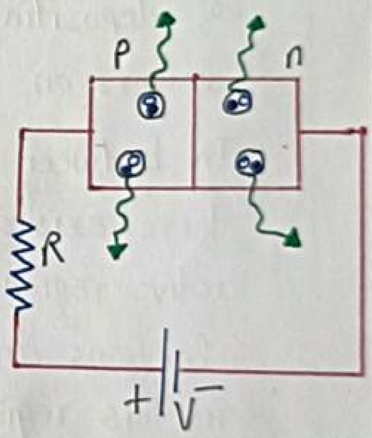
The LED can emit light in all the directions from the layered structure.
This layered structure is packed in a tiny reflective cup so as to make the light directed towards the desired exit direction.

Working Principle of LED



Cup type structure of LED

Whenever a p-n junction is forward-biased, the electrons cross the p-n junction from the n-type semiconductor material and recombine with the holes. When a free electron recombines with a hole, it falls from the conduction band to valence band. Thus the energy level associated with it changes from higher value to lower value. The energy corresponding to the difference between higher level and lower level is released by electrons while travelling from the conduction band to the valence band.

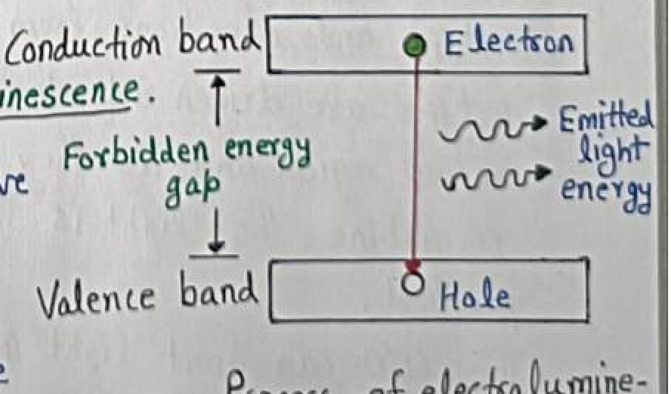


Forward-biased LED

In normal diodes [Ge, Si], the energy is released in the form of heat within the structure and the emitted light is insignificant.

So the LED is made up of some special materials which release this energy in the form of photons or light energy. Hence the diode is called Light emitting diode.

This process is known as electroluminescence.



Process of electroluminescence

The energy released due to radiative recombination depends on the forbidden energy gap (E_g) which determines the wavelength and the color of the emitted light.

The wavelength (λ) of emitted light is given by

$$\lambda(\mu m) = \frac{1.24}{E_g[eV]}$$