Maa Omwati Degree Collage Hassanpur

NOTES

Subject:- Electromagnatic Indtuction And Electronic Devices

B.SC Sem:-II

Session :2020-21

UNIT- I
PN DIODE CHARACTERISTICS

Introduction:

Electronics Engineering is a branch of engineering which deals with the flow of electrons in vacuum tube gas and semiconductor.

Applications of Electronics:
Home Appliances, Medical Applications, Robotics, Mobile Communication, Computer Communication et

Atomic Structure:

- Atom is the basic building block of all the elements. It consists of the central nucleus of positi charge around which small negatively charged particles called electrons revolve in different paths orbits.
- An Electrostatic force of attraction between electrons and the nucleus holds up electrons in differe orbits.

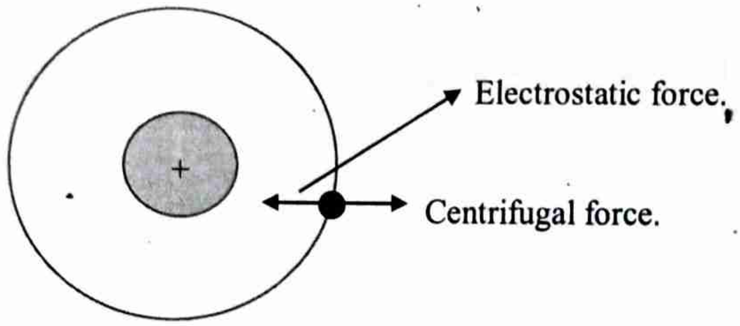


Figure 1.1: Atomic structure

- Nucleus is the central part of an atom and contains protons and neutrons. A proton is positive charged particle, while the neutron has the same mass as the proton, but has no charge. Therefoı nucleus of an atom is positively charged.
- **atomic weight = no. of protons + no. of neutrons**
- An electron is a negatively charged particle having negligible mass. The charge on an electron equal but opposite to that on a proton. Also the number of electrons is equal to the number of proto in an atom under ordinary conditions. Therefore an atom is neutral as a whole.
- **atomic number = no. of protons or electrons in an atom**
- The number of electrons in any orbit is given by $2n^2$ where n is the number of the orbit.

  For example, I orbit contains $2x1^2 = 2$ electrons

  II orbit contains $2x2^2 = 8$ electrons

  III orbit contains $2x3^2 = 18$ electrons and so on
- The last orbit cannot have more than 8 electrons.
- The last but one orbit cannot have more than 18 electrons.

Positive and negative ions:

- Protons and electrons are equal in number hence if an atom loses an electron it has lost negati charge therefore it becomes positively charged and is referred as positive ion.
- If an atom gains an electron it becomes negatively charged and is referred to as negative ion.

Valence electrons:

The electrons in the outermost orbit of an atom are known as valence electrons.

- The outermost orbit can have a maximum of 8 electrons.
- The valence electrons determine the physical and chemical properties of a material.
- When the number of valence electrons of an atom is less than 4, the material is usually a metal and conductor. Examples are sodium, magnesium and aluminium, which have 1,2 and 3 valen electrons respectively.
- When the number of valence electrons of an atom is more than 4, the material is usually a non-me and an insulator. Examples are nitrogen, sulphur and neon, which have 5,6 and 8 valence electro respectively.
- When the number of valence electrons of an atom is 4 the material has both metal and non-me properties and is usually a semi-conductor. Examples are carbon, silicon and germanium.

Free electrons:

- The valence electrons of different material possess different energies. The greater the energy ol valence electron, the lesser it is bound to the nucleus.
- In certain substances, particularly metals, the valence electrons possess so much energy that they a very loosely attached to the nucleus.
- The loosely attached valence electrons move at random within the material and are called fr electrons.

The valence electrons, which are loosely attached to the nucleus, are known as free electrons.

Energy bands:

- In case of a single isolated atom an electron in any orbit has definite energy.
- When atoms are brought together as in solids, an atom is influenced by the forces from other aton Hence an electron in any orbit can have a range of energies rather than single energy. These range energy levels are known as Energy bands.
- Within any material there are two distinct energy bands in which electrons may exist viz , Valen band and conduction band.

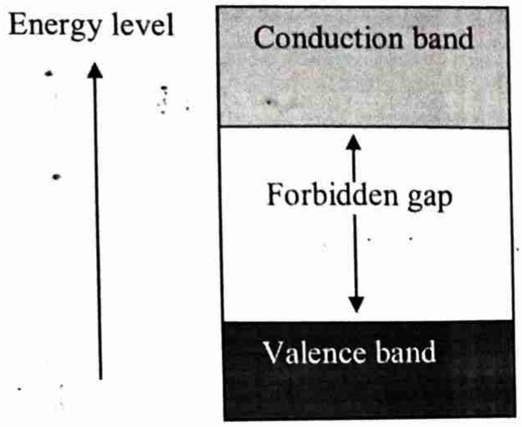


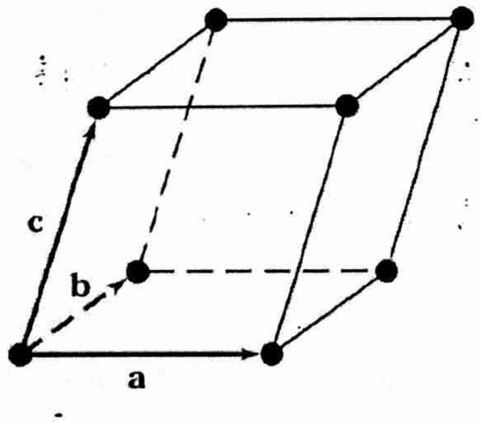
Figure 1.2: Energy level diagram

- **The range of energies possessed by valence electrons is called valence band.**
- **The range of energies possessed by free electrons is called conduction band.**
- **Valence band and conduction band are separated by an energy gap in which no electro normally exist this gap is called forbidden gap.**

Electrons in conduction band are either escaped from their atoms (free electrons) or only weakly held the nucleus. Thereby by the electrons in conduction band may be easily moved around within the material applying relatively small amount of energy. (either by increasing the temperature or by focusing light on t material etc.) This is the reason why the conductivity of the material increases with increase in temperatur

But much larger amount of energy must be applied in order to extract an electron from the valence ba because electrons in valence band are usually in the normal orbit around a nucleus. For any given materi the forbidden gap may be large, small or non-existent.

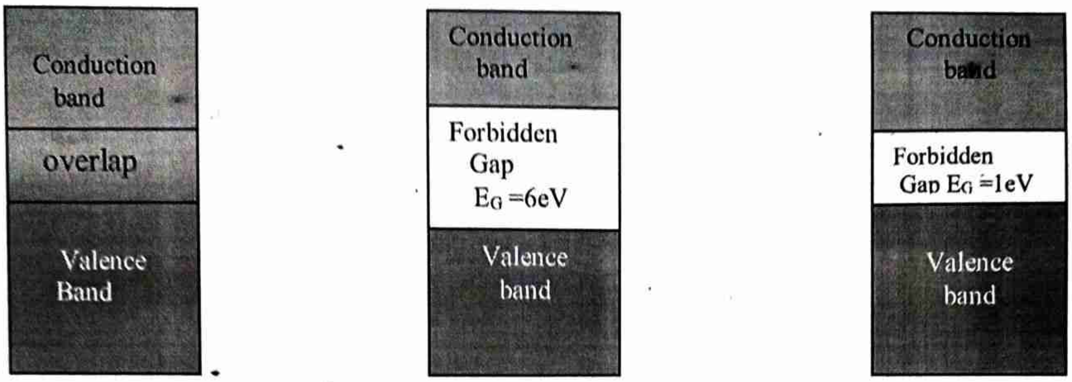
The periodic arrangement of atoms is called lattice. A unit cell of a material represents the Entire lattice. I repeating the unit cell throughout the crystal, one can generate the entire lattice.



Classification of materials based on Energy band theory:

Based on the width of the forbidden gap, materials are broadly classified as

- Conductors
- Insulators
- Semiconductors.



(a) Conductor (b) Insulator (c) Semiconductor

Conductors:

- Conductors are those substances, which allow electric current to pass through them.
  Example: Copper, Al, salt solutions, etc.
- In terms of energy bands, conductors are those substances in which there is no forbidden ga
  Valence and conduction band overlap as shown in fig (a).
- For this reason, very large number of electrons are available for conduction even at extremely lc temperatures. Thus, conduction is possible even by a very weak electric field.

Insulators:

- Insulators are those substances, which do not allow electric current to pass through them.
  Example: Rubber, glass, wood etc.
- In terms of energy bands, insulators are those substances in which the forbidden gap is very large.
- Thus valence and conduction band are widely separated as shown in fig (b). Therefore insulators not conduct electricity even with the application of a large electric field or by heating or at very hi temperatures.

Semiconductors:

- Semiconductors are those substances whose conductivity lies in between that of a conductor a Insulator.
  Example: Silicon, germanium, Cealenium, Gallium, arsenide etc.
- In terms of energy bands, semiconductors are those substances in which the forbidden gap is narrov
- Thus valence and conduction bands are moderately separated as shown in fig(C).
- In semiconductors, the valence band is partially filled, the conduction band is also partially fille and the energy gap between conduction band and valence band is narrow.
- Therefore, comparatively smaller electric field is required to push the electrons from valence band conduction band . At low temperatures the valence band is completely filled and conduction band completely empty. Therefore, at very low temperature a semi-conductor actually behaves as insulator.

Conduction in solids:

- Conduction in any given material occurs when a voltage of suitable magnitude is applied to it, whi causes the charge carriers within the material to move in a desired direction.

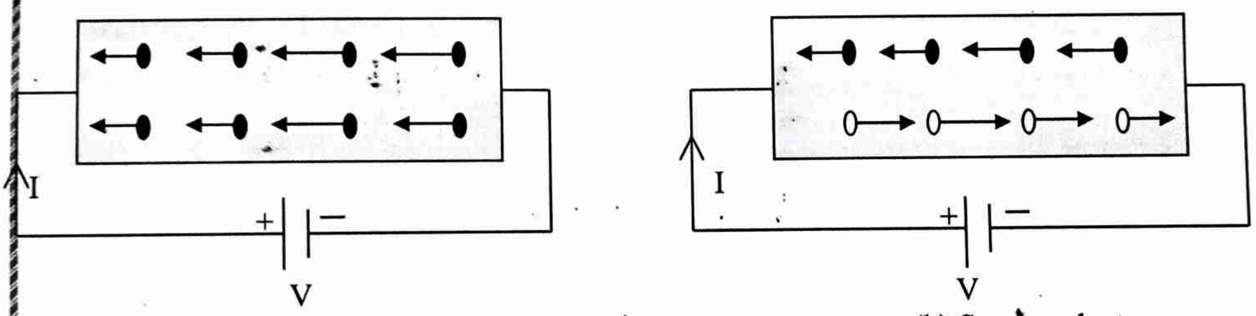
- This may be due to electron motion or hole transfer or both.

Electron motion:

Free electrons in the conduction band are moved under the influence of the applied electric fiel Since electrons have negative charge they are repelled by the negative terminal of the applied voltage a attracted towards the positive terminal.

Hole transfer:

- Hole transfer involves the movement of holes.
- Holes may be thought of positive charged particles and as such they move through an electric field a direction opposite to that of electrons.



(a) Conductor

(b) Semiconductor

← Flow of electrons

→ Flow of current

← Flow of electrons

→ Flow of holes

→ Flow of current

- In a good conductor (metal) as shown in fig (a) the current flow is due to free electrons only.

- In a semiconductor as shown in fig (b). The current flow is due to both holes and electrons moving opposite directions.

- The unit of electric current is Ampere (A) and since the flow of electric current is constituted by t movement of electrons in conduction band and holes in valence band, electrons and holes a referred as charge carriers.

Classification of semiconductors:

Semiconductors are classified into two types.

a) Intrinsic semiconductors.
b) Extrinsic semiconductors.

a) Intrinsic semiconductors:

- **A semiconductor in an extremely pure form is known as Intrinsic semiconductor.**
  Example: Silicon, germanium.

- Both silicon and Germanium are tetravalent (having 4 valence electrons).

- Each atom forms a covalent bond or electron pair bond with the electrons of neighboring atoı The structure is shown below.

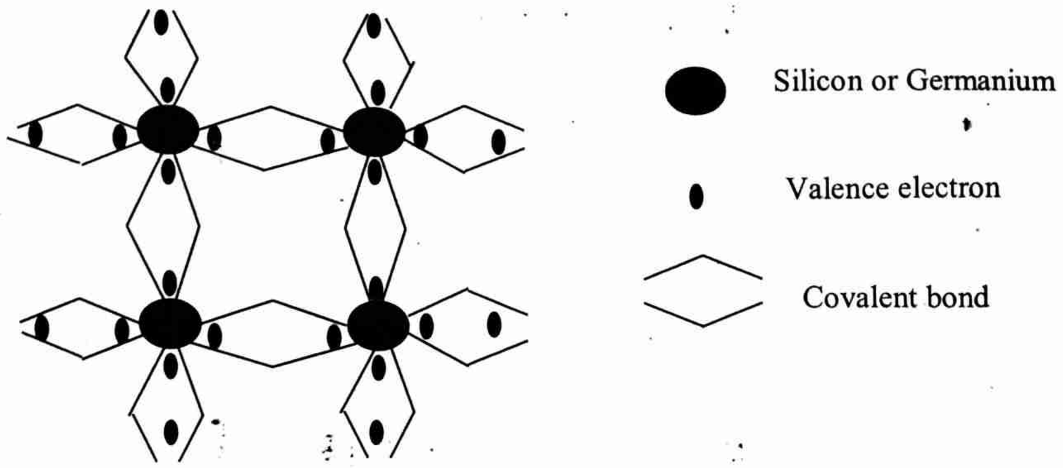


Figure 1.3: Crystalline structure of Silicon (or Germanium)

At low temperature

- At low temperature, all the valence electrons are tightly bounded the nucleus hence no free electro are available for conduction.
- The semiconductor therefore behaves as an Insulator at absolute zero temperature.

At room temperature

- At room temperature, some of the valence electrons gain enough thermal energy to break up t covalent bonds.
- This breaking up of covalent bonds sets the electrons free and is available for conduction.
- When an electron escapes from a covalent bond and becomes free electrons a vacancy is created ir covalent bond as shown in figure above. Such a vacancy is called Hole. It carries positive charge a: moves under the influence of an electric field in the direction of the electric field applied.
- Numbers of holes are equal to the number of electrons since; a hole is nothing but an absence electrons.

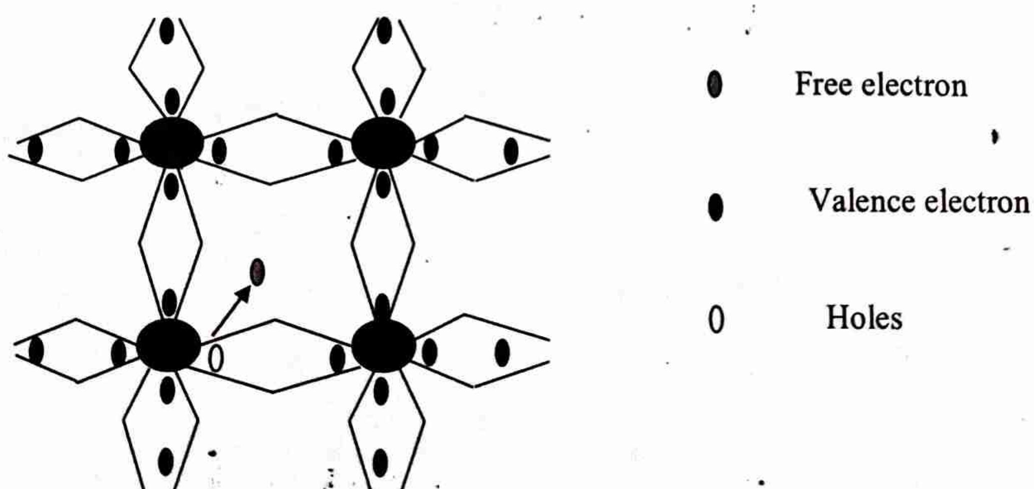


Figure 1.4: Crystalline structure of Silicon (or Germanium) at room temperature

<u>**Extrinsic Semiconductor:**</u>

- When an impurity is added to an intrinsic semiconductor its conductivity changes.
- This process of adding impurity to a semiconductor is called Doping and the impure semiconduct is called extrinsic semiconductor.

- Depending on the type of impurity added, extrinsic semiconductors are further classified as n-ty and p-type semiconductor.

N-type semiconductor:

- **When a small current of Pentavalent impurity is added to a pure semiconductor it is called n-type semiconductor.**
- Addition of Pentavalent impurity provides a large number of free electrons in a semiconduct crystal.
- Typical example for pentavalent impurities are Arsenic, Antimony and Phosphorus etc. Su impurities which produce n-type semiconductors are known as Donor impurities because they dona or provide free electrons to the semiconductor crystal.
- To understand the formation of n-type semiconductor, consider a pure silicon crystal with impurity say arsenic added to it as shown in figure 1.5.
- We know that a silicon atom has 4 valence electrons and Arsenic has 5 valence electrons. Wh Arsenic is added as impurity to silicon, the 4 valence electrons of silicon make co-valent bond w 4 valence electrons of Arsenic.
- The 5th Valence electrons finds no place in the covalent bond thus, it becomes free and travels to t conduction band as shown in figure. Therefore, for each arsenic atom added, one free electron will available in the silicon crystal. Though each arsenic atom provides one free electrons yet extremely small amount of arsenic impurity provides enough atoms to supply millions of fr electrons.

Due to thermal energy, still hole election pairs are generated but the number of free electrons are very lar in number when compared to holes. So in an n-type semiconductor electrons are majority charge carrie and holes are minority charge carriers . Since the current conduction is pre-dominantly by free electrons vely charges) it is called as n-type semiconductor(n- means –ve).

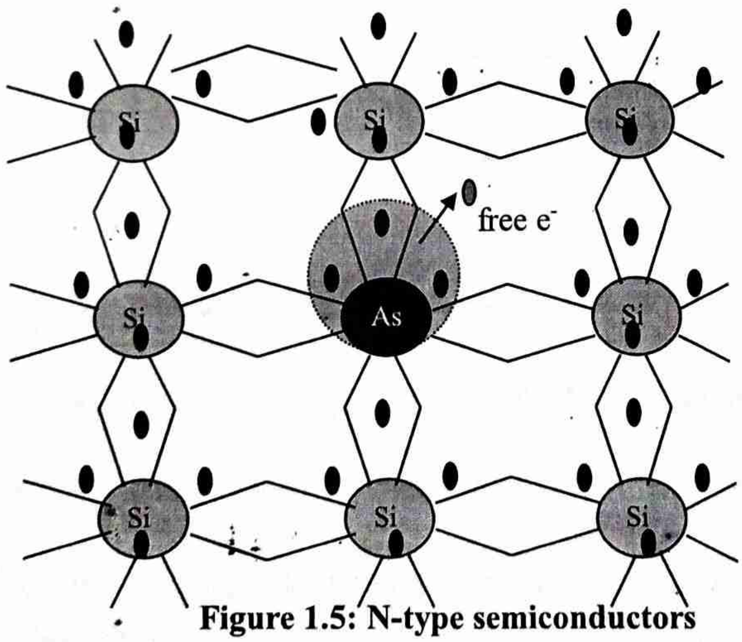
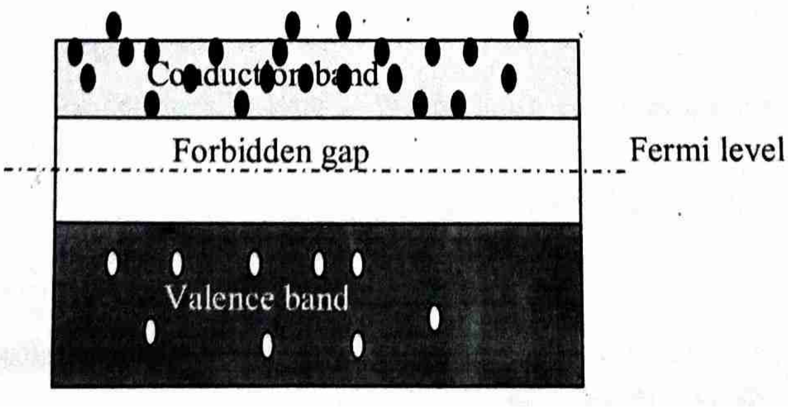


Figure 1.5: N-type semiconductors



P-type semiconductor:

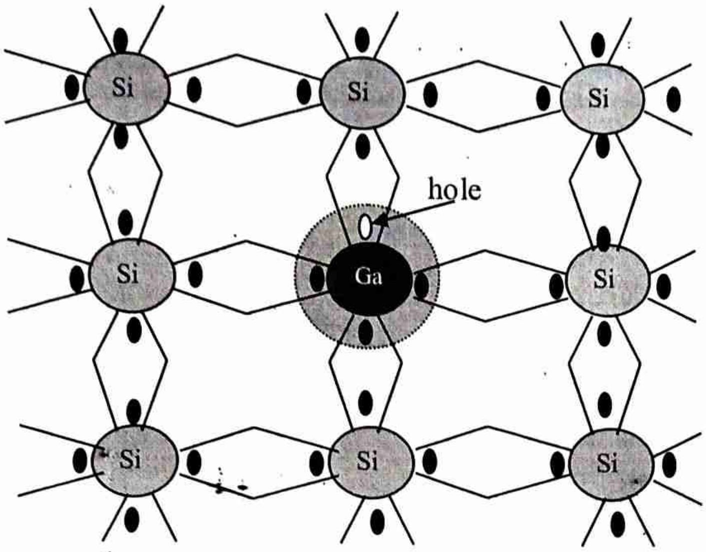


Figure 1.7: P-type semiconductor

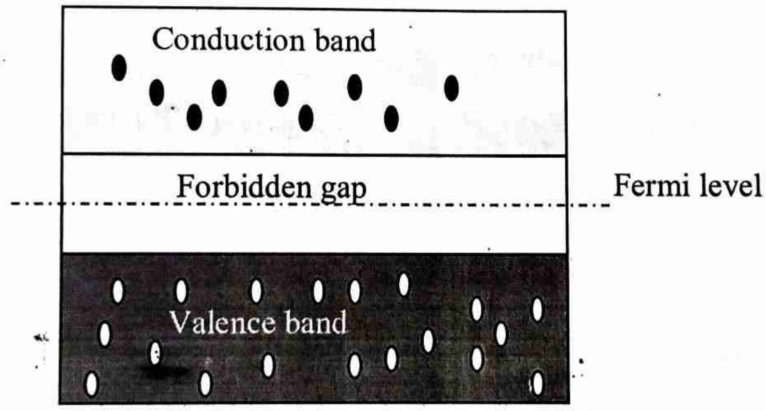


Figure 1.8: Energy band diagram for p-type semiconductor

- When a small amount of trivalent impurity is added to a pure semiconductor it is called p-ty semiconductor.
- The addition of trivalent impurity provides large number of holes in the semiconductor crystals.
- Example: Gallium, Indium or Boron etc. Such impurities which produce p-type semiconductors ε known as acceptor impurities because the holes created can accept the electrons in the seı conductor crystal.

To understand the formation of p-type semiconductor, consider a pure silicon crystal with an impurity s gallium added to it as shown in figure.7.

- We know that silicon atom has 4 valence electrons and Gallium has 3 electrons. When Gallium added as impurity to silicon, the 3 valence electrons of gallium make 3 covalent bonds with 3 valen electrons of silicon.
- The 4th valence electrons of silicon cannot make a covalent bond with that of Gallium because short of one electron as shown above. This absence of electron is called a hole. Therefore for ea gallium atom added one hole is created, a small amount of Gallium provides millions of holes.

Due to thermal energy, still hole-electron pairs are generated but the number of holes is very large compar to the number of electrons. Therefore, in a p-type semiconductor holes are majority carriers and electrons a minority carriers. Since the current conduction is predominantly by hole(+ charges) it is called as p-ty semiconductor (p means +ve)

PN Junction Diode:

When a p-type semiconductor material is suitably joined to n-type semiconductor the cont surface is called a p-n junction. The p-n junction is also called as semiconductor diode.

Applications of diode:

i) Used as rectifier diodes in DC power suppliers .
ii) Used as clippers and clampers
iii) Used as switch in logic circuit in computers
iv) Used as voltage multipliers.

Construction and working of a PN Junction diode:

Open Circuited PN Junction:

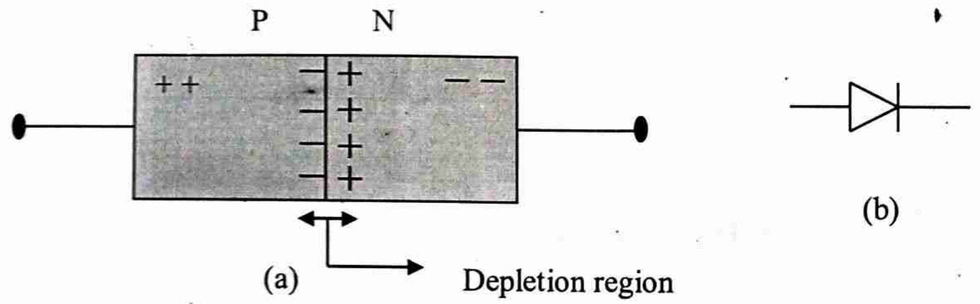


Figure 1.9 (a): p-n junction **Figure 1.9 (b): Symbolic representation**

- The left side material is a p-type semiconductor having –ve acceptor ions and +vely charged hol The right side material is n-type semiconductor having +ve donor ions and free electrons.

- Suppose the two pieces are suitably treated to form pn junction, then there is a tendency for the fr electrons from n-type to diffuse over to the p-side and holes from p-type to the n-side . This proce is called **diffusion.**

- As the free electrons move across the junction from n-type to p-type, +ve donor ions are uncover Hence a +ve charge is built on the n-side of the junction. At the same time, the free electrons cr the junction and uncover the –ve acceptor ions by filling in the holes. Therefore a net –ve charge established on p-side of the junction.

- When a sufficient number of donor and acceptor ions is uncovered further diffusion is prevented.

- Thus a barrier is set up against further movement of charge carriers. This is called potential barrier junction barrier Vo. The potential barrier is of the order of 0.1 to 0.3V.

Note: outside this barrier on each side of the junction, the material is still neutral. Only inside the barri there is a +ve charge on n-side and –ve charge on p-side. This region is called depletion layer.

Biasing of a PN junction diode:

Connecting a p-n junction to an external DC voltage source is called biasing.

1. Forward biasing
2. Reverse biasing

1. Forward biasing

- When external voltage applied to the junction is in such a direction that it cancels the potent barrier, thus permitting current flow is called forward biasing.

- To apply forward bias, connect +ve terminal of the battery to p-type and –ve terminal to n-type shown in fig.2.1 below.

- The applied forward potential(V_F) establishes the electric field which acts against the field due potential barrier. Therefore the resultant field is weakened and the barrier height is reduced at t junction as shown in fig. 2.1.

- Since the potential barrier voltage is very small, a small forward voltage(V_F) is sufficient completely eliminate the barrier. Once the potential barrier is eliminated by the forward voltag junction resistance (R_F) becomes almost zero and a low resistance path is established for the enti circuit. Therefore current flows in the circuit. This is called forward current (I_F).

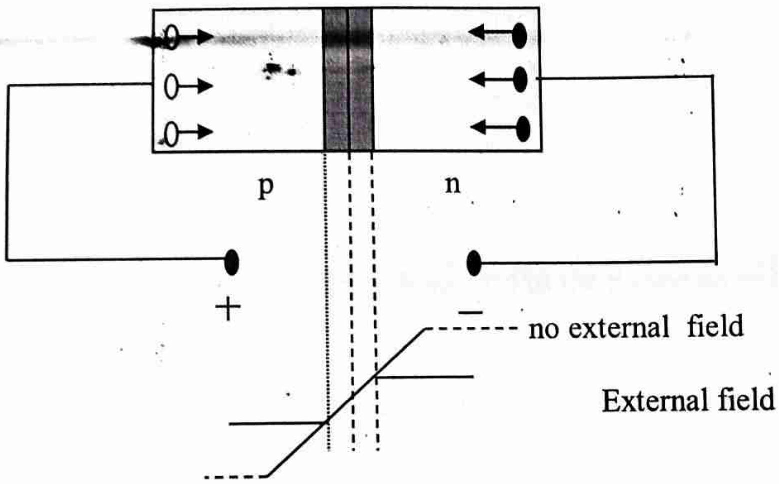


Figure 1.10: Forward biasing of p-n junction

2. Reverse biasing

- When the external voltage applied to the junction is in such a direction the potential barrier increased it is called reverse biasing.

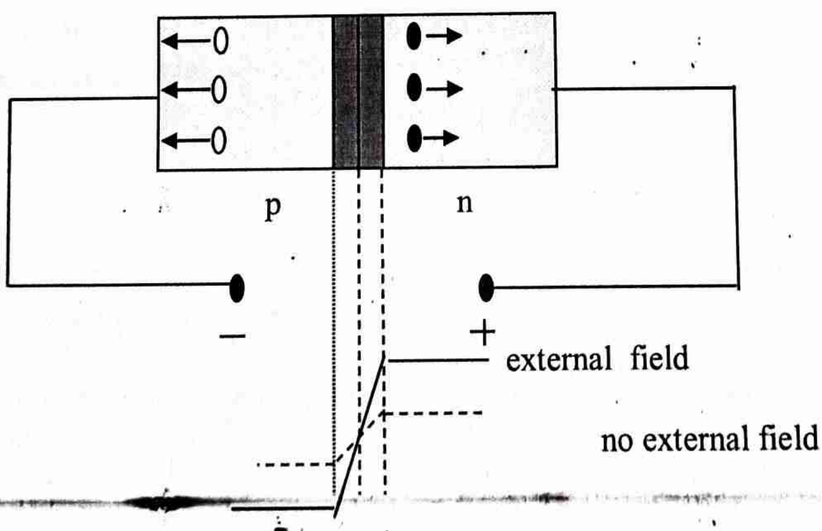


Figure 1.11: Reverse biasing of p-n junction

- To apply reverse bias, connect –ve terminal of the battery to p-type and +ve terminal to n-type shown in figure below.

- The applied reverse voltage establishes an electric field which acts in the same direction as the fie due to potential barrier. Therefore the resultant field at the junction is strengthened and the barri height is increased as shown in fig.2.2.

- The increased potential barrier prevents the flow of charge carriers across the junction. Thus a hi resistance path (R_R) is established for the entire circuit and hence current does not flow. But practice a very little current flows due to minority charge carriers. The current is called rever saturation current (I_S).

Volt- Ampere characteristics (V-I) of a PN junction diode:

1. **Forward Bias** - The voltage potential is connected positive, (+ve) to the P-type material a negative, (-ve) to the N-type material across the diode which has the effect of **Decreasing** the PN-juncti width.

2. **Reverse Bias** - The voltage potential is connected negative, (-ve) to the P-type material and positi (+ve) to the N-type material across the diode which has the effect of **Increasing** the PN-junction width

Forward Biased Junction Diode:

When a diode is connected in a **Forward Bias** condition, a negative voltage is applied to the type material and a positive voltage is applied to the P-type material.

If this external voltage (V_F) becomes greater than the value of the potential barrier (V_γ), appro 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome a current will start to flow. This current is called forward current(I_F)

This is because the negative voltage pushes or repels electrons towards the junction giving the the energy to cross over and combine with the holes being pushed in the opposite direction towards t junction by the positive voltage.

This results in a characteristics curve of zero current flowing up to this voltage point, called t "knee" on the static curves and then a high current flow through the diode with little increase in the exterr voltage as shown below.

Forward Characteristics:

Case 1:

When the applied forward voltage $V_F < V_\gamma$, the width of the depletion layer is increased and no curre flows through the circuit.

Case 2:

When the applied forward voltage $V_F > V_\gamma$, the charge carriers move towards the junction from P N and from N to P, due to this the width of the junction gets reduced and at one particular voltage t junction gets damaged ,and forward resistance(R_F) offered by the diode will be very less (ideally 0) d to this there will be a flow of current due to majority charge carriers. The current is said to be forwa current (I_F) which will be very large.

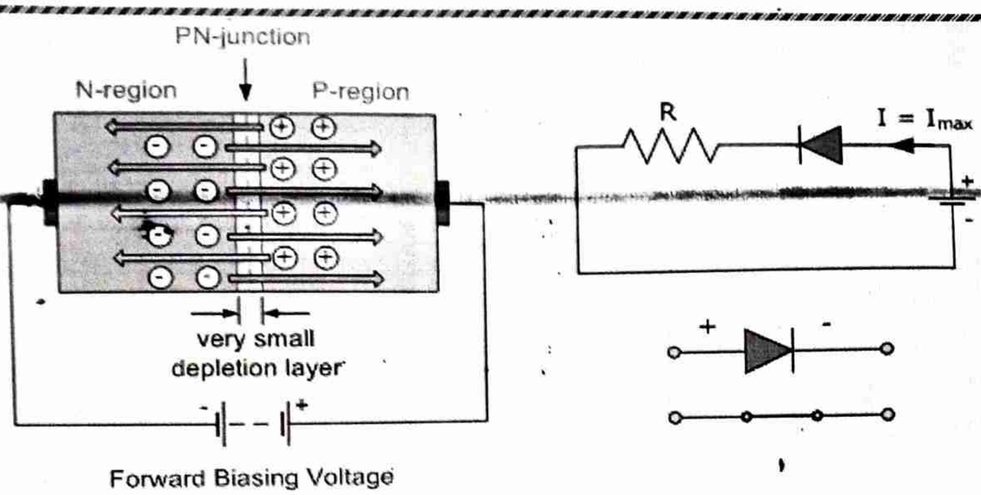


Figure 1.12: Forward Biased Junction Diode showing a Reduction in the Depletion Layer

This condition represents the low resistance path through the PN junction allowing very lar currents to flow through the diode with only a small increase in bias voltage. The actual potential differen across the junction or diode is kept constant by the action of the depletion layer at approximately 0.3v f germanium and approximately 0.7v for silicon junction diodes. Since the diode can conduct "infinit current above this knee point as it effectively becomes a short circuit, therefore resistors are used in seri with the diode to limit its current flow.

Reverse Biased Junction Diode:

When a diode is connected in a **Reverse Bias** condition, a positive voltage is applied to the N-ty material and a negative voltage is applied to the P-type material.

The positive voltage applied to the N-type material attracts electrons towards the positive electro and away from the junction, while the holes in the P-type end are also attracted away from the juncti towards the negative electrode.

The net result is that the depletion layer grows wider due to a lack of electrons and holes an presents a high impedance path, almost an insulator. The result is that a high potential barrier is created th preventing current from flowing through the semiconductor material.

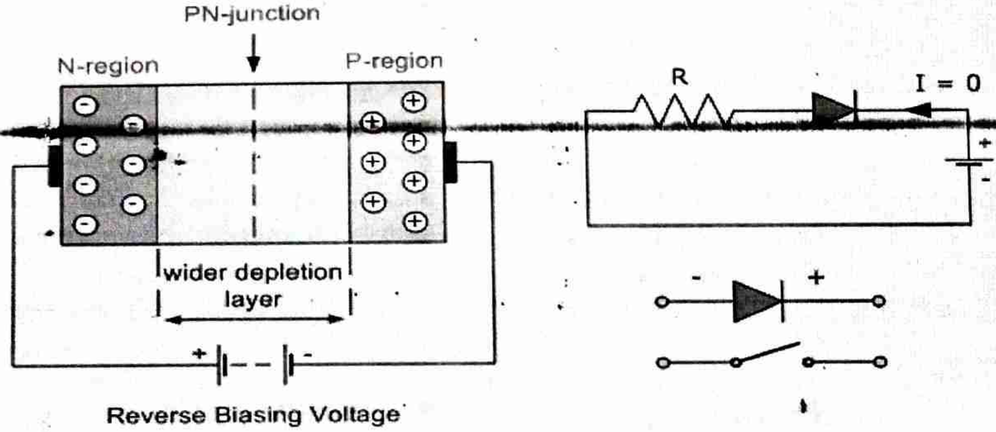


Figure 1.13: Reverse Biased Junction Diode showing an Increase in the Depletion Layer

This condition represents a high resistance value to the PN junction and practically zero curre flows through the junction diode with an increase in bias voltage. However, a very small **leakage curre (Is)** does flow through the junction which can be measured in microamperes, (μA). One final point, if t reverse bias voltage Vr applied to the diode is increased to a sufficiently high enough value, it will cause t PN junction to overheat and fail due to the avalanche effect around the junction. This may cause the diode become shorted and will result in the flow of maximum circuit current and this shown as a step downwa slope in the reverse static characteristics curve below.

Sometimes this avalanche effect has practical applications in voltage stabilising circuits where series limiting resistor is used with the diode to limit this reverse breakdown current to a preset maximu value thereby producing a fixed voltage output across the diode. These types of diodes are commonly knov as **Zener Diodes.**

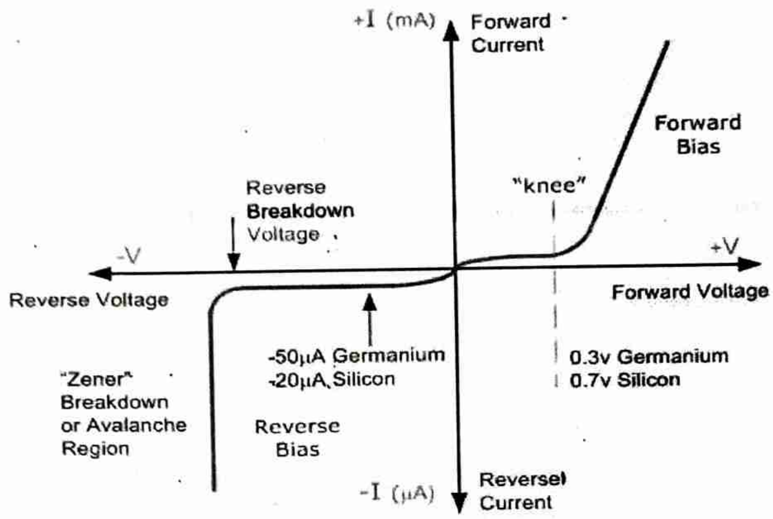


Figure 1.14: V-I Characteristics of PN Junction Diode

PN diode Currents:

The expression for the total current as a function of the applied voltage is derived below.

Here we neglect the depletion layer thickness and hence assume that the barrier width is 0. I: forward bias is applied to the diode, the holes are injected from P side to n material. The concentration holes in the side is increased above its thermal equilibrium value P_n and given by ,

$$P_n(x) = P_{no} + P_{n(o)}e^{-x/LP}. \text{-------- (1)}$$

Where,

L_P is called the diffusion length for holes in 'n' material and the injected or excess concentration X = 0 is

$$P_n(o) = P_n(o) - P_{no} \text{ ....(2)}$$

These several hole concentration components are indicated in figure which shows t exponential decrease of the density $P_n(x)$ with distance X into the n material.

The diffusion hole concentration components are indicated, in figure, which shows t exponential decrease the density $P_n(x)$ with distance x into the n material. The diffusion hole current the n side is given by

$$ipn = -\,Ae\, D_P d_{pn}/dp_x \quad \text{....(3)}$$

Sub (1) in (3) we obtain

$$ip_n(x) = \frac{A_e D_P P_n(o)e^{-x/LP}}{L_P} \text{.......(4)}$$

This equation verifies that the hole current decreases exponentially with distance. The dependen of Ipn up to applied voltage is contained implicitly in the factor P_n (o) because the injected concentrati is a function of voltage. We now find the dependence of $P_n(o)$ upon V.

Law of junction:

If the hole concentration at the edges of space charge region as P_n and P_P in the P and n materia respectively and if the barrier potential across this depletion layer V_B, then

$$P_P = P_n e^{V_B/V_T} \quad ....(5)$$

[redacted]

open Cktd on junction, then

$$P_p = P_{PO},\ P_n = O_{no} \text{ and } V_B = V_o.$$

At the edge of depletion layer $X = 0$, $P_n = P_n(o)$.

The Boltzmann relation, i.e for this case.

$$P_{PO} = P_n(O)e^{(V_0 - V)/V_T} \quad ......(6)$$

Combining this equation with $V_0/V_T = E_0/KT$.

$$P_n(O) = P_{no}e^{V/VT} \quad ......(7)$$

This boundary condition is called the law of junction.

The hole concentration P_n (O) injected into n side at the junction is obtained by subs equation (6) equation (2)

[redacted]

The Forward Currents:-

The hole current IPn(O) crossing the junction into n side is given by equation (4) we obtain

$$IPn(O) = \frac{A_e D_P P_{no}}{L_P}(e^{V/V_T} - 1) \quad .....(9)$$

The election current InP (O) crossing junction into P side is obtained from equation 9 l interchanging n & P or

$$InP(O) = \frac{A_e D_P n_{po}}{L_n}(e^{V/V_T} - 1) \quad .....(10)$$

Total diode current is given by

$$I = I_{Pn}(O) + I_{NP}(O)$$

$$I = I_o\left(e^{V/VT} - 1\right)$$

Temperature dependence of V-I characteristics of p-n junction diode:

The temperature has following effects on the diode parameters,

1. The cut-in voltage decreases as the temperature increases. The diode conducts at smaller voltage at large temperature.
2. The reverse saturation current increases as temperature increases.

This increases in reverse current I_o is such that it doubles at every 10 °C rise in temperatu Mathematically,

$$I_{o2} = 2^{(\Delta T/10)} I_{o1}$$

where I_{o2} = Reverse current at T_2 °C
I_{o1} = Reverse current at T_1 C
$\Delta T = (T_2 - T_1)$

3. The voltage equivalent of temperature V_T also increases as temperature increases.
4. The reverse breakdown voltage increases as temperature increases as shown.

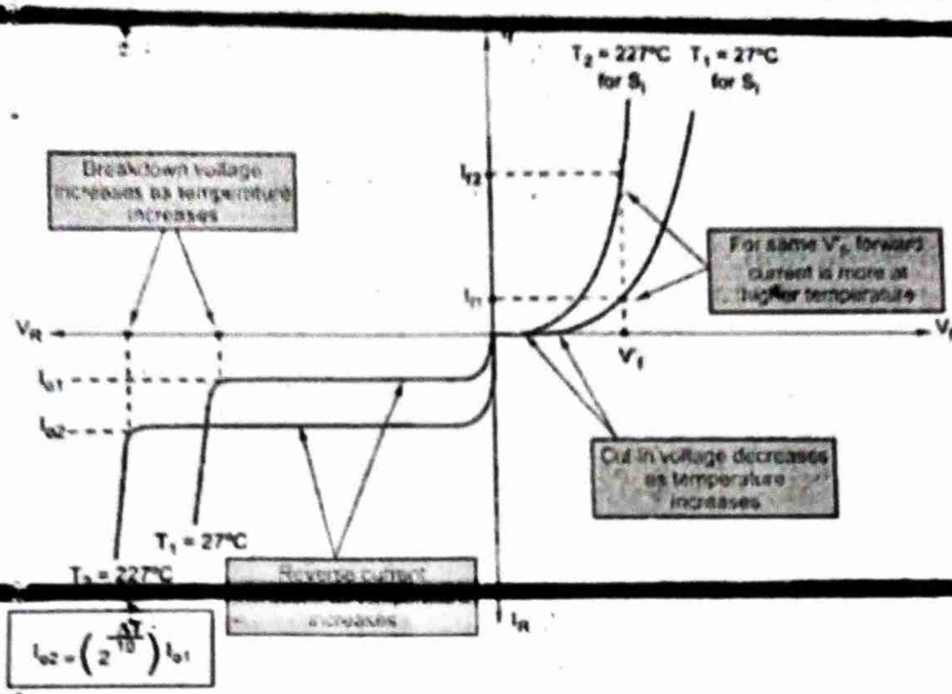


Figure 1.15: Effect of Temperature on PN Diode characteristics

(a) Effect of Temperature on forward voltage drop:

Most of the times, the drop across the diode is assumed constant. But in few situations, it is necessary consider the effect of temperature on forward voltage drop.

It is seen that cut-in voltage decreases as temperature increases.

Note :The diode forward voltage drop decrease as temperature increases.

The rate at which it increases is - 2.3 mV/ °C for silicon while - 2.12 mV/ °C for germanium. T negative sign shows decrease in forward voltage drop as temperature increases. This is shown in figu below.

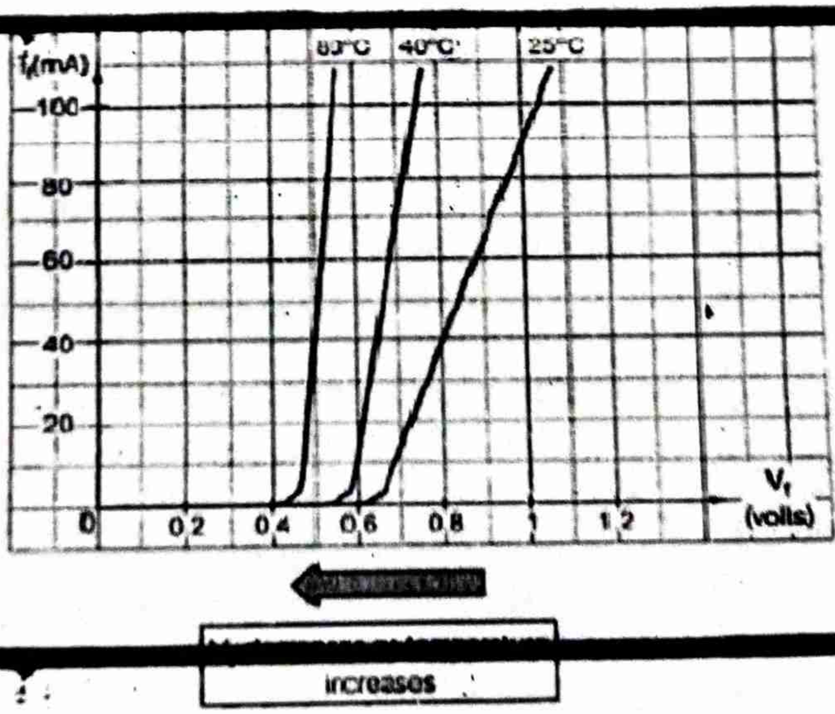


Figure 1.15: Effect of Temperature on forward voltage drop

The coefficient $\Delta V_f / °C$ is called voltage/temperature coefficient of diode. Knowing this and V_{f1} at T_1, a V_{f2} at T_2 can be obtained as,

$$V_{f_2} = V_{f1} + [\Delta T \times \text{Voltage / temperature coefficient}] \quad \text{... (4)}$$

(b) Effect of Temperature on Dynamic Resistance:

The dynamic resistance of the diode is obtained as,

$$r_f' = \frac{26\text{ mV}}{I_f} = \frac{V_T}{I_f} = \frac{kT}{I_f}$$

where k = Boltzman's constant and T in °K constant.

The value 26 mV is temperature dependent and the above equation is applicable only at 25 °C. For higher temperatures, it gets changed as,

$$r_f' = \frac{kT'}{I_f} \quad \text{... (}$$

where T' is new temperature in °K.

The above equation can be expressed as,

$$r_f' = \frac{26\text{ mV}}{I_f}\left[\frac{T' \text{ in °K}}{298\text{ °C}}\right] \quad \text{... ((}$$

Note : As temperature increases, V_T increase hence dynamic forward resistance increases.

Diode Junction capacitance:

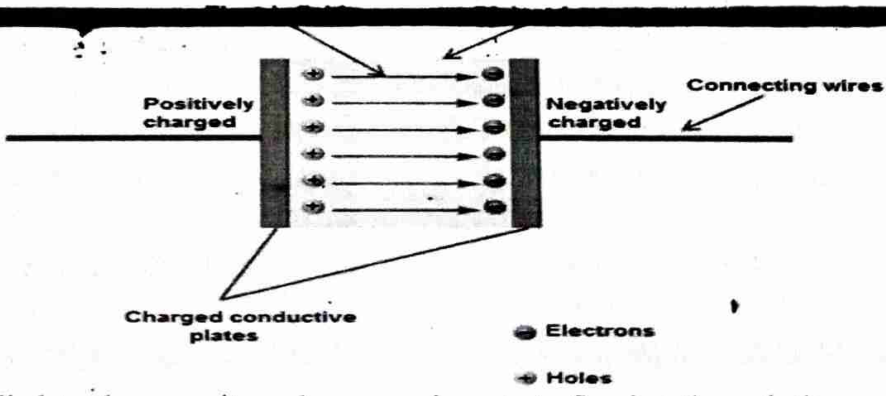
In a p-n junction diode, two types of capacitance take place. They are,

- Transition capacitance (C_T)
- Diffusion capacitance (C_D)

(a) Transition capacitance (C_T):

We know that capacitors store electric charge in the form of electric field. This charge storage is done using two electrically conducting plates (placed close to each other) separated by an insulating mater called dielectric.

The conducting plates or electrodes of the capacitor are good conductors of electricity. Therefore, they easi allow electric current through them. On the other hand, dielectric material or medium is poor conductor electricity. Therefore, it does not allow electric current through it. However, it efficiently allows electı field.



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

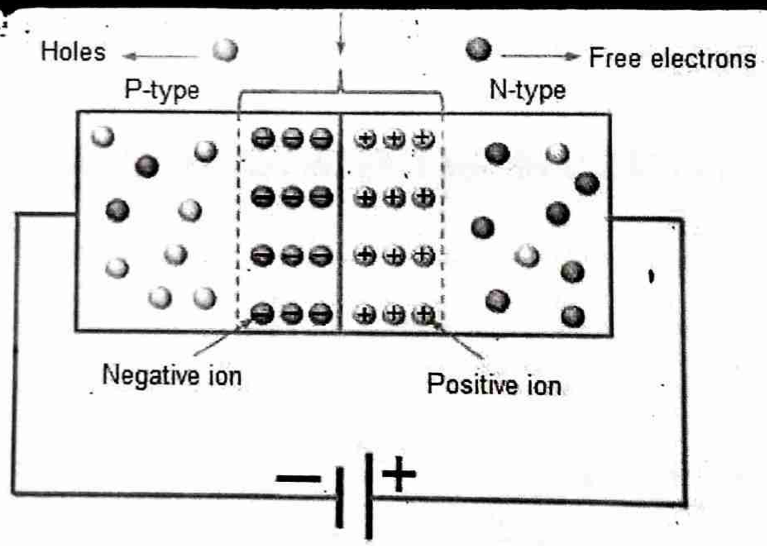
In a basic capacitor, the capacitance is directly proportional to the size of electrodes or plates and inverse proportional to the distance between two plates.

Just like the capacitors, a reverse biased p-n junction diode also stores electric charge at the depletion regic The depletion region is made of immobile positive and negative ions.

In a reverse biased p-n junction diode, the p-type and n-type regions have low resistance. Hence, p-type a n-type regions act like the electrodes or conducting plates of the capacitor. The depletion region of the p junction diode has high resistance. Hence, the depletion region acts like the dielectric or insulating materi: Thus, p-n junction diode can be considered as a parallel plate capacitor.

In depletion region, the electric charges (positive and negative ions) do not move from one place to anoth place. However, they exert electric field or electric force. Therefore, charge is stored at the depletion regi in the form of electric field. The ability of a material to store electric charge is called capacitance. Thu there exists a capacitance at the depletion region.

[redacted]



[redacted]

Figure 1.16: Transition Capacitance

The capacitance at the depletion region changes with the change in applied voltage. When reverse bi voltage applied to the p-n junction diode is increased, a large number of holes(majority carriers) from p-si and electrons (majority carriers) from n-side are moved away from the p-n junction. As a result, the width depletion region increases whereas the size of p-type and n-type regions (plates) decreases.

We know that capacitance means the ability to store electric charge. The p-n junction diode with narrc depletion width and large p-type and n-type regions will store large amount of electric charge whereas the n junction diode with wide depletion width and small p-type and n-type regions will store only a sm: amount of electric charge. Therefore, the capacitance of the reverse bias p-n junction diode decreases wh voltage increases.

In a forward biased diode, the transition capacitance exist. However, the transition capacitance is very sm: compared to the diffusion capacitance. Hence, transition capacitance is neglected in forward biased diode.

[redacted] capacitance is also known as depletion region capacitance, junction capacitance or barrier capacitanc Transition capacitance is denoted as C_T.

The change of capacitance at the depletion region can be defined as the change in electric charge per chan in voltage.

$$C_T = dQ / dV$$

Where,

C_T = Transition capacitance
dQ = Change in electric charge
dV = Change in voltage

The transition capacitance can be mathematically written as,

$$C_T = \varepsilon A / W$$

Where,

[redacted]

A = Area of plates or p-type and n-type regions
W = Width of depletion region

Diffusion capacitance (C_D):

Diffusion capacitance occurs in a forward biased p-n junction diode. Diffusion capacitance is al sometimes referred as storage capacitance. It is denoted as C_D.
In a forward biased diode, diffusion capacitance is much larger than the transition capacitance. Henc diffusion capacitance is considered in forward biased diode.
The diffusion capacitance occurs due to stored charge of minority electrons and minority holes near t depletion region.
When forward bias voltage is applied to the p-n junction diode, electrons (majority carriers) in the n-regi will move into the p-region and recombines with the holes. In the similar way, holes in the p-region w [redacted]

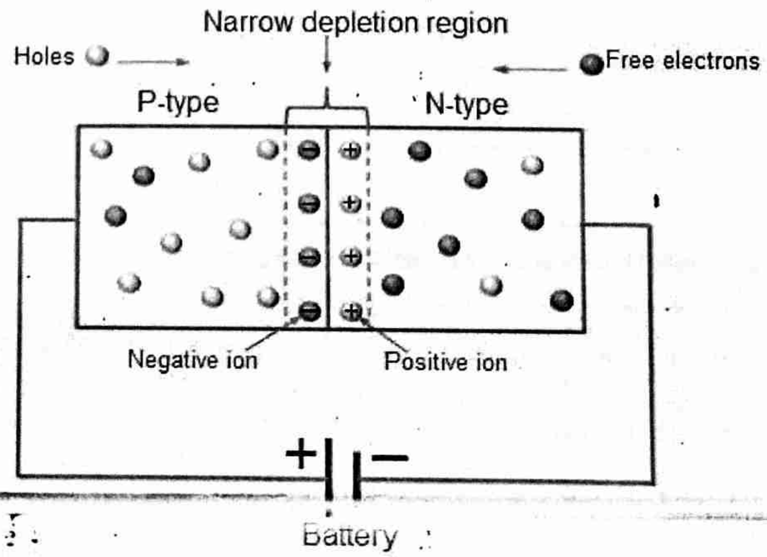


Figure 1.17: Diffusion Capacitance

The electrons (majority carriers) which cross the depletion region and enter into the p-region will becor minority carriers of the p-region similarly; the holes (majority carriers) which cross the depletion region ai enter into the n-region will become minority carriers of the n-region.

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

The accumulation of holes in the n-region and electrons in the p-region is separated by a very thin depleti region or depletion layer. This depletion region acts like dielectric or insulator of the capacitor and char stored at both sides of the depletion layer acts like conducting plates of the capacitor.

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

In the similar way, if small electric current flows through the diode, only a small amount of charge accumulated near the depletion layer. As a result, small diffusion capacitance occurs.

When the width of depletion region decreases, the diffusion capacitance increases. The diffusion capacitan value will be in the range of nano farads (nF) to micro farads (μF).

The formula for diffusion capacitance is

$$C_D = dQ / dV$$

Where,

C_D = Diffusion capacitance

dQ = Change in number of minority carriers stored outside the depletion region

[redacted]

Energy Band Diagram of P-N Diode:

For an n-type semiconductor, the Fermi level E_F lies near the conduction band edge. E_C but for an p - type semiconductor, E_F lies near the valance band edge E_V.

E_C

E_F

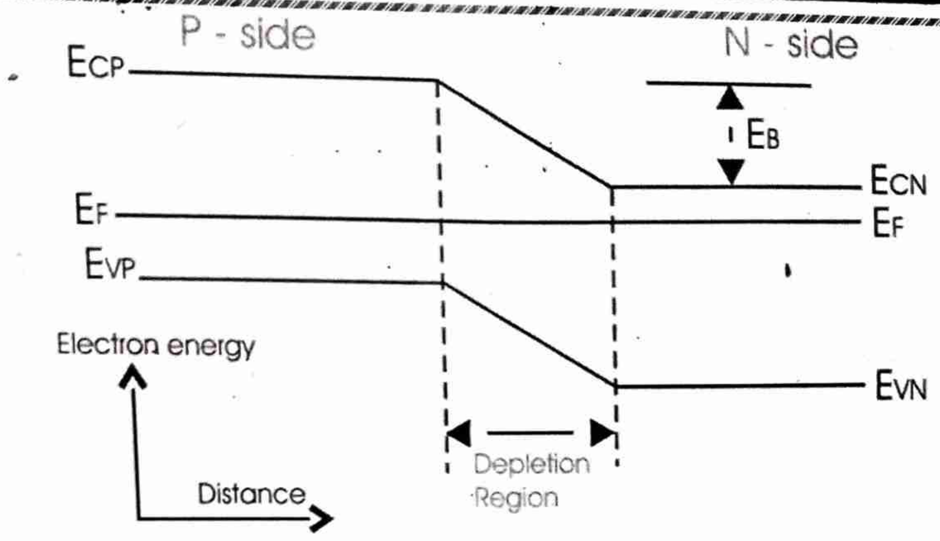
E_V

E_C

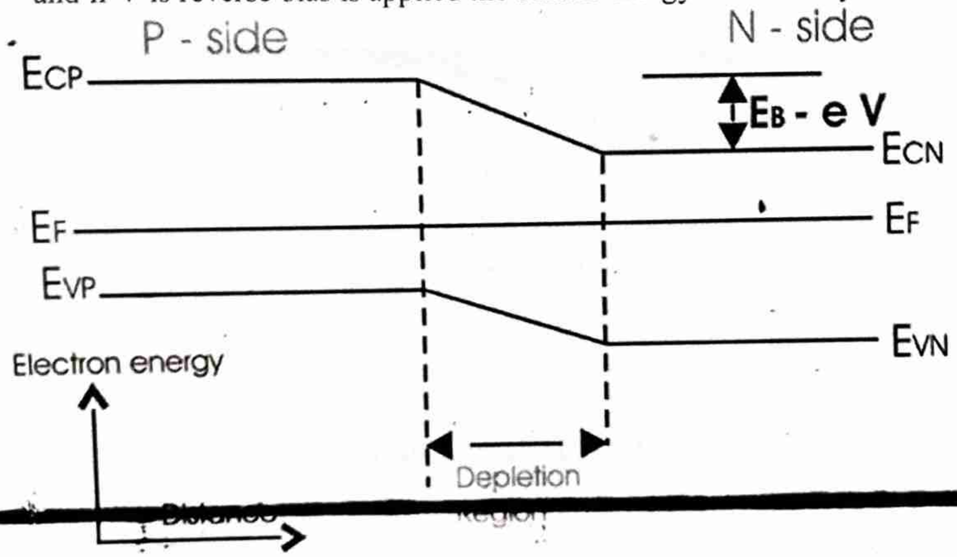
E_F

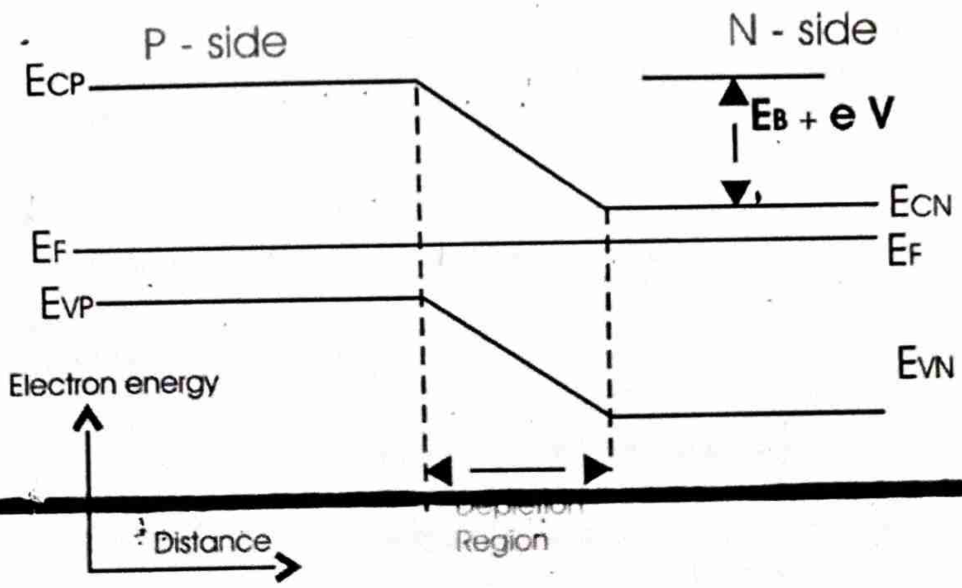
E_V

Now, when a p-n junction is built, the Fermi energy E_F attains a constant value. In this scenario the p-sid conduction band edge. Similarly n–side valance band edge will be at higher level than E_{cn}, n-sid conduction band edge of p - side. This energy difference is known as barrier energy. The barrier energy is] $= E_{cp} - E_{cn} = E_{vp} - E_{vn}$



If we apply forward bias voltage V, across junction then the barrier energy decreases by an amount of eV and if V is reverse bias is applied the barrier energy increases by eV.





Static and Dynamic Resistances:

(a) DC or Static Resistance :

The application of a dc voltage to a circuit containing a semiconductor diode will result in an operating poi on the characteristic curve that will not change with time. The resistance of the diode at the operating poi can be found simply by finding the Corresponding levels of V_D and I_D as shown in Fig. 1.18 and applyi the following Equation:

$$R_D = \frac{V_D}{I_D}$$

The dc resistance levels at the knee and below will be greater than the resistance levels obtained for t vertical rise section of the characteristics. The resistance levels in the reverse-bias region will naturally quite high. Since ohmmeters typically employ a relatively constant-current source, the resistance determin will be at a preset current level (typically, a few mill amperes).

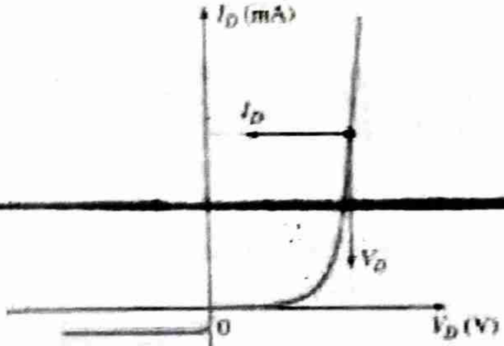


Figure 1.18: Determining the dc resistance of a diode at a particular operating point

(b) AC or Dynamic Resistance :

It is obvious from the above equation of static resistance that the dc resistance of a diode is independent the shape of the characteristic in the region surrounding the point of interest. If a sinusoidal rather than input is applied, the situation will change completely.

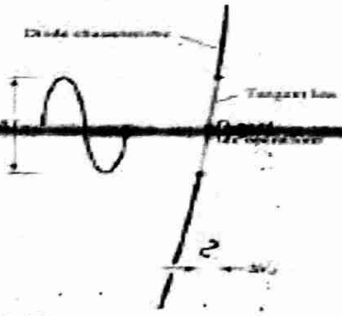


Figure 1.19: Defining the ac resistance of a diode

The varying input will move the instantaneous operating point up and down a region of the characteristi and thus defines a specific change in current and voltage as shown in Fig. 1.19. With no applied varyi signal, the point of operation would be the Q-point appearing on Fig. 1.19 determined by the applied levels. The designation *Q-point* is derived from the word *quiescent,* which means —still or unvarying.

A straight line drawn tangent to the curve through the Q-point as shown in Fig. 1.20 will define a particul change in voltage and current that can be used to determine the *ac* or *dynamic resistance* for this region the diode characteristics. In equation form,

$$r_d = \frac{\Delta V_d}{\Delta I_d}$$

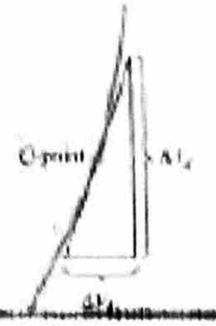


Figure 1.20: Determining the ac resistance of a diode at Q point

Diode Equivalent Circuits:

An equivalent circuit is a combination of elements properly chosen to best represent the actual termin characteristics of a device, system, or such in a particular operating region. In other words, once t equivalent circuit is defined, the device symbol can be removed from a schematic and the equivalent circu inserted in its place without severely affecting the actual behavior of the system. The result is often network that can be solved using traditional circuit analysis techniques.

(a) Piecewise-Linear Equivalent Circuit :

One technique for obtaining an equivalent circuit for a diode is to approximate the characteristics of t device by straight-line segments, as shown in Fig. 1.21. The resulting equivalent circuit is naturally call the *piecewise-linear equivalent circuit.* It should be obvious from Fig. 1.21 that the straight-line segments not result in an exact duplication of the actual characteristics, especially in the knee region. However, t resulting segments are sufficiently close to the actual curve to establish an equivalent circuit that w provide an excellent first approximation to the actual behavior of the device. The ideal diode is included establish that there is only one direction of conduction through the device, and a reverse-bias condition w result in the open circuit state for the device. Since a silicon semiconductor diode does not reach t conduction state until V_D reaches 0.7 V with a forward bias (as shown in Fig. 1.21), a battery V_T opposi the conduction direction must appear in the equivalent circuit as shown in Fig. 1.21. The battery simp specifies that the voltage across the device must be greater than the threshold battery voltage befo conduction through the device in the direction dictated by the ideal diode can be established. Wh conduction is established the resistance of the diode will be the specified value of r_{av}.

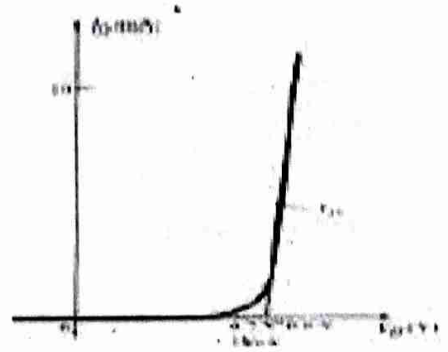


Figure 1.21: Defining the piecewise-linear equivalent circuit using straight-line segments to approximate the characteristic curve

The approximate level of *rav* can usually be determined from a specified operating point on the specificati sheet. For instance, for a silicon semiconductor diode, if I_F =10 mA (a forward conduction current for t diode) at V_D = 0.8 V, we know for silicon that a shift of 0.7 V is required before the characteristics rise.

$$r_{av} = \left.\frac{\Delta V_d}{\Delta I_d}\right|_{\text{pt. to pt.}} = \frac{0.8\text{ V} - 0.7\text{ V}}{10\text{ mA} - 0\text{ mA}} = \frac{0.1\text{ V}}{10\text{ mA}} = 10\ \Omega$$

(b) Simplified Equivalent Circuits :

For most applications, the resistance r_{av} is sufficiently small to be ignored in comparison to the oth elements of the nêtwork. The removal of r_{av} from the equivalent circuit is the same as implying that t characteristics of the diode. Under dc conditions has a drop of 0.7 V across it in the conduction state at a level of diode current.

(c) Ideal Equivalent Circuits:

Now that r_{av} has been removed from the equivalent circuit let us take it a step further and establish that 0.7-V level can often be ignored in comparison to the applied voltage level. In this case the equivalent circı will be reduced to that of an ideal diode as shown in Fig. 1.22 with its characteristics.

Figure 1.22: Ideal diode and its characteristics

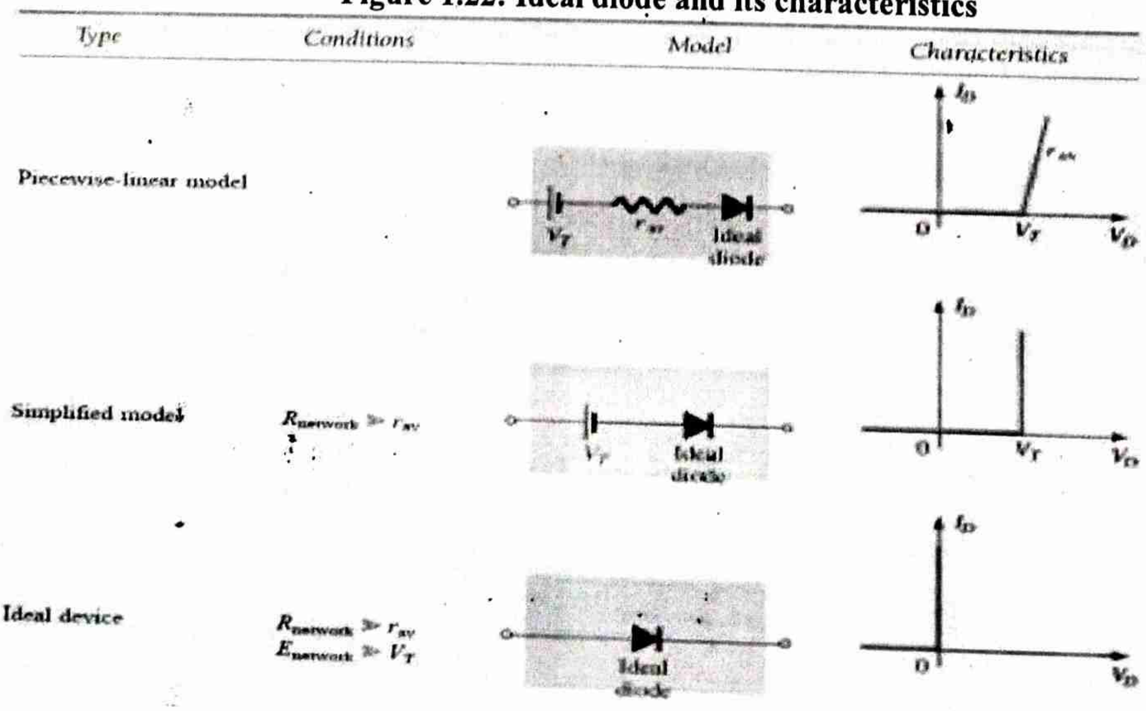


Figure 1.23: **Diode equivalent circuits**

Rectifiers and Filters:

Introduction:

For the operation of most of the electronics devices and circuits, a d.c. source is required. So it is advantageous to convert domestic a.c. supply into d.c. voltages. The process of converting a.c. voltage into d.c. voltage is called as rectification. This is achieved with i) Step-down Transformer, ii) Rectifier, iii) Filter and iv) Voltage regulator circuits.

These elements constitute d.c. regulated power supply shown in the figure below.

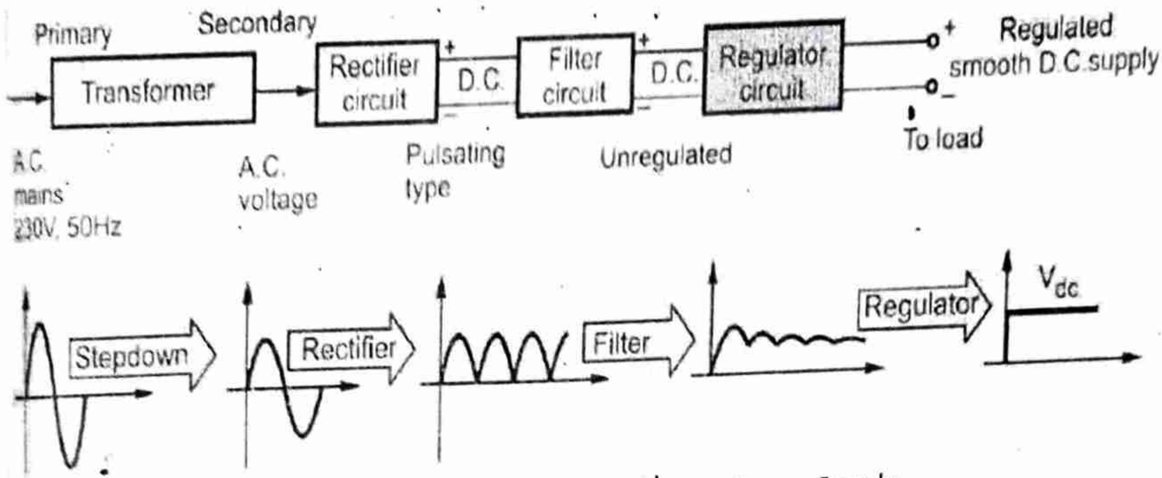


Fig. Block diagram of Regulated D.C. Power Supply

The block diagram of a regulated D.C. power supply consists of step-down transformer, rectifier, filter, voltage regulator and load.

An ideal regulated power supply is an electronics circuit designed to provide a predetermined d.c. voltage Vo which is independent of the load current and variations in the input voltage ad temperature.

If the output of a regulator circuit is a AC voltage then it is termed as voltage stabilizer, whereas if the output is a DC voltage then it is termed as voltage regulator.

The elements of the regulated DC power supply are discussed as follows:

TRANSFORMER:

A transformer is a static device which transfers the energy from primary winding to secondary winding through the mutual induction principle, without changing the frequency. The transformer winding to which the supply source is connected is called the primary, while the winding connected to the load is called secondary.

If N_1, N_2 are the number of turns of the primary and secondary of the transformer then $\alpha = \frac{N_2}{N_1}$ is called the turns ratio of the transformer.

The different types of the transformers are

- Step-Up Transformer
- Step-Down Transformer
- Centre-tapped Transformer

The voltage, current and impedance transformation ratios are related to the turns ratio of the transformer by the following expressions.

Voltage transformation ratio : $\frac{V_2}{V_1} = \frac{N_2}{N_1}$

Current transformation ratio : $\frac{I_2}{I_1} = \frac{N_1}{N_2}$

Impedance transformation ratio : $\frac{Z_L}{Z_{in}} = \left(\frac{N_2}{N_1}\right)^2$

RECTIFIER:

Any electrical device which offers a low resistance to the current in one direction but a high resistance to the current in the opposite direction is called rectifier. Such a device is capable of converting a sinusoidal input waveform, whose average value is zero, into a unidirectional waveform, with a non-zero average component.

A rectifier is a device which converts a.c. voltage (bi-directional) to pulsating d.c. voltage (Uni-directional).

Important characteristics of a Rectifier Circuit:

1. **Load currents:** They are two types of output current. They are average or d.c. current and RMS currents.

i) **Average or DC current:** The average current of a periodic function is defined as the area of one cycle of the curve divided by the base.

It is expressed mathematically as $I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i\,d(\omega t)$; where $i = I_m \sin \omega t$

6) **Effective (or) R.M.S. current:** The effective (or) R.M.S. current squared of a periodic function of time is given by the area of one cycle of the curve which represents the square of the function divided by the base.

It is expressed mathematically as $I_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} i^2 d(\omega t)\right]^{\frac{1}{2}}$

2. **Load Voltages:** There are two types of output voltages. They are average or D.C. voltage and R.M.S. voltage.

i) **Average or DC Voltage:** The average voltage of a periodic function is defined as the areas of one cycle of the curve divided by the base. It is expressed mathematically as

$$V_{dc} = \frac{1}{2\pi}\int_0^{2\pi} V\,d(\omega t) \text{ ; Where } V = V_m \sin \omega t$$

$$\text{(or) } V_{dc} = I_{dc} \times R_L$$

ii) **Effective (or) R.M.S Voltage:** The effective (or) R.M.S voltage squared of a periodic function of time is given by the area of one cycle of the curve which represents the square of the function divided by the base.

$$V_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} V^2 d(\omega t)\right]^{\frac{1}{2}} \qquad V_{rms} = I_{rms} \times R_L$$

3. **Ripple Factor (γ) :** It is defined as ration of R.M.S. value of a.c. component to the d.c. component in the output is known as "Ripple Factor".

$$\gamma = \frac{V_{rms}}{V_{dc}}$$

$$V_{rms} = \sqrt{V_{rms}^2 - V_{dc}^2}$$

$$\therefore \gamma = \sqrt{\frac{V_{rms}}{V_{dc}} - 1}$$

4. **Efficiency (η) :** It is the ratio of d.c output power to the a.c. input power. It signifies, how efficiently the rectifier circuit converts a.c. power into d.c. power.

It is given by $$\eta = \frac{P_{dc}}{P_{Ac}}$$

5. **Peak Inverse Voltage (PIV):** It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction.

6. **Regulation:** The variation of the d.c. output voltage as a function of d.c. load current is called regulation. The percentage regulation is defined as

$$\text{\% Regulation} = \frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100\%$$

For an ideal power supply, % Regulation is zero.

Using one or more diodes in the circuit, following rectifier circuits can be designed.

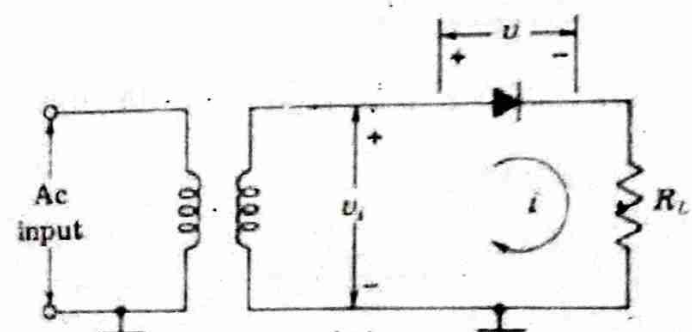
1. Half - Wave Rectifier
2. Full – Wave Rectifier
3. Bridge Rectifier

HALF-WAVE RECTIFIER:

A Half – wave rectifier is one which converts a.c. voltage into a pulsating voltage using only one half cycle of the applied a.c. voltage. The basic half-wave diode rectifier circuit along with its input and output waveforms is shown in figure below.

The half-wave rectifier circuit shown in above figure consists of a resistive load; a rectifying element i.e., p-n junction diode and the source of a.c. voltage, all connected is series. The a.c. voltage is applied to the rectifier circuit using step-down transformer.

The input to the rectifier circuit, $V = V_m \sin \omega t$ Where Vm is the peak value of secondary a.c. voltage



(a)

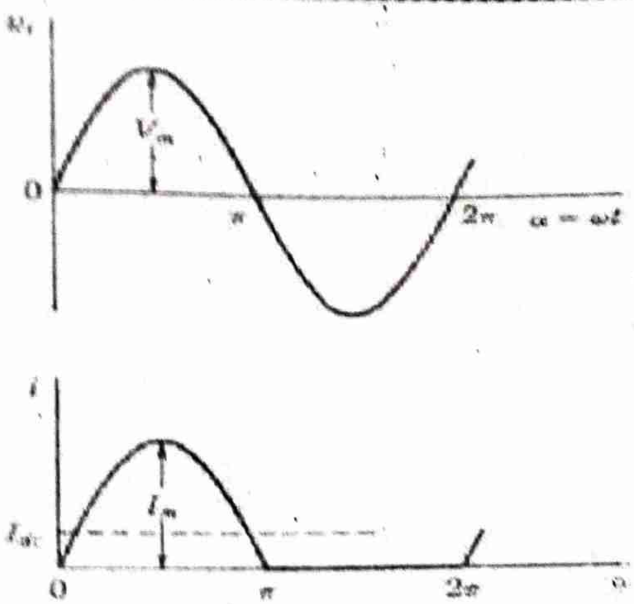


Figure 1.24: Circuit and Waveforms of half wave rectifier

Operation:

For the positive half-cycle of input a.c. voltage, the diode D is forward biased and hence it conducts. Now a current flows in the circuit and there is a voltage drop across R_L. The waveform of the diode current (or) load current is shown in figure.

For the negative half-cycle of input, the diode D is reverse biased and hence it does not conduct. Now no current flows in the circuit i.e., i=0 and Vo=0. Thus for the negative half-cycle no power is delivered to the load.

Analysis:

In the analysis of a HWR, the following parameters are to be analyzed.

i) DC output current
ii) DC Output voltage
iii) R.M.S. Current
iv) R.M.S. voltage
v) Rectifier Efficiency (η)
vi) Ripple factor (γ)
vii) Regulation
viii) Transformer Utilization Factor (TUF)
ix) Peak Factor (P)

Let a sinusoidal voltage V_i be applied to the input of the rectifier.

Then $V = V_m \sin \omega t$ Where Vm is the maximum value of the secondary voltage.

Let the diode be idealized to piece-wise linear approximation with resistance R_f in the forward direction i.e., in the ON state and R_r (=∞) in the reverse direction i.e., in the OFF state.

Now the current 'i' in the diode (or) in the load resistance R_L is given by

$$i = I_m \sin \omega t \quad \text{for} \quad 0 \le \omega t \le \pi$$

$$i = 0 \quad \text{for} \quad \pi \le \omega t \le 2\pi$$

$$\text{where } I_m = \frac{V_m}{R_f + R_L}$$

i) **Average (or) DC Output Current (I_{av} or I_{dc}):**

The average dc current I_{dc} is given by

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i\,d(\omega t)$$

$$= \frac{1}{2\pi}\int_0^{\pi} I_m \sin \omega t\,d(\omega t) + \int_{\pi}^{2\pi} 0 \times d(\omega t)$$

$$= \frac{1}{2\pi} I_m (-\cos \omega t)_0^{\pi}$$

$$= \frac{1}{2\pi} I_m (+1 - (-1))$$

$$= \frac{I_m}{\pi} = 0.318\, I_m$$

Substituting the value of I_m, we get $I_{dc} = \frac{V_m}{\pi(R_f + R_L)}$

If $R_L >> R_f$ then $I_{dc} = \frac{V_m}{\pi R_L} = 0.318 \frac{V_m}{R_L}$

ii) **Average (or) DC Output Voltage (V_{av} or V_{dc}):**

The average dc voltage is given by

$$V_{dc} = I_{dc} \times R_L = \frac{I_m}{\pi} \times R_L = \frac{V_m R_L}{\pi(R_f + R_L)}$$

$$\Rightarrow V_{dc} = \frac{V_m R_L}{\pi(R_f + R_L)}$$

If $R_L >> R_f$ then $V_{dc} = \frac{V_m}{\pi} = 0.318\, I_m$ $\quad \therefore V_{dc} = \frac{V_m}{\pi}$

iii) RMS output current (I_{rms}):

The value of the R.M.S. current is given by

$$I_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} i^2 d(\omega t)\right]^{\frac{1}{2}}$$

$$= \left[\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2 \omega t.d(\omega t) + \frac{1}{2\pi}\int_{\pi}^{2\pi} 0 \cdot d(\omega t)\right]^{\frac{1}{2}}$$

$$= \left[\frac{I_m^2}{2\pi}\int_0^{\pi}\frac{1-\cos 2\omega t}{2}\, d(\omega t)\right]^{\frac{1}{2}}$$

$$= \left[\frac{I_m^2}{4\pi}\left|(\omega t) - \frac{1}{2}\sin 2\omega t\right|_0^{\pi}\right]^{\frac{1}{2}}$$

$$= \left[\frac{I_m^2}{4\pi}\left(\pi - 0 - \frac{\sin 2\pi}{2} + \sin 0\right)\right]^{\frac{1}{2}}$$

$$= \left[\frac{I_m^2}{4}\right]^{\frac{1}{2}} = \frac{I_m}{2}$$

$$\therefore I_{rms} = \frac{I_m}{2} \qquad I_{rms} = \frac{V_m}{2(R_f + R_L)}$$

iv) R.M.S. Output Voltage (V_{rms}):

R.M.S. voltage across the load is given by

$$V_{rms} = I_{rms} \times R_L = \frac{V_m R_L}{2(R_f + R_L)} = \frac{V_m}{2\left(1 + \frac{R_f}{R_L}\right)}$$

If $R_L >> R_f$ then $V_{rms} = \frac{V_m}{2}$

v) Rectifier efficiency(η) :

The rectifier efficiency is defined as the ration of d.c. output power to the a.c. input power i.e.,

$$\eta = P_{dc}/P_{ac}$$

Theoretically the maximum value of rectifier efficiency of a half-wave rectifier is 40.6%

viii) Transformer Utilization Factor (UTF):

The d.c. power to be delivered to the load in a rectifier circuit decides the rating of the transformer used in the circuit. So, transformer utilization factor is defined as

$$\therefore TUF = \frac{P_{dc}}{P_{ac\,(rated)}}$$

The factor which indicates how much is the utilization of the transformer in the circuit is called Transformer Utilization Factor (TUF).

The a.c. power rating of transformer $= V_{rms} I_{rms}$

The secondary voltage is purely sinusoidal hence its rms value is $\frac{1}{\sqrt{2}}$ times maximum while the current is half sinusoidal hence its rms value is $\frac{1}{2}$ of the maximum.

$$\therefore P_{ac\,(rated)} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{2} = \frac{V_m I_m}{2\sqrt{2}}$$

The d.c. power delivered to the load $= I_{dc}^2 R_L = \left(\frac{I_m}{\pi}\right)^2 R_L$

$$\therefore TUF = \frac{P_{dc}}{P_{ac\,(rated)}}$$

$$= \left(\frac{I_m}{\pi}\right)^2 R_L \times \frac{2\sqrt{2}}{V_m I_m}$$

$$= \frac{I_m^2 \cdot R_L \cdot 2\sqrt{2}}{\pi^2 \; I_m \cdot I_m R_L} \qquad (\because V_m \approx I_m R_L)$$

$= 0.287$

$$\therefore TUF = 0.287$$

The value of TUF is low which shows that in half-wave circuit, the transformer is not fully utilized.

If the transformer rating is 1 KVA (1000VA) then the half-wave rectifier can deliver 1000 X 0.287 = 287 watts to resistance load.

ix) Peak Inverse Voltage (PIV):

It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction. The peak inverse voltage across a diode is the peak of the negative half-cycle. For half-wave rectifier, PIV is V_m.

x) Form factor (F):

The Form Factor F is defined as

F = rms value / average value

$$F = \frac{I_m/2}{I_m/\pi}$$

$$F = \frac{0.5\,I_m}{0.318\,I_m} = 1.57$$

xi) Peak Factor (P):

The peak factor P is defined as

$$P = \text{Peak Value / rms value} = \frac{V_m}{V_m/2} = 2 \qquad P = 2$$

Disadvantages of Half-Wave Rectifier:

1. The ripple factor is high.
2. The efficiency is low.
3. The Transformer Utilization factor is low.

Because of all these disadvantages, the half-wave rectifier circuit is normally not used as a power rectifier circuit.

Problems from previous external question paper:

1. A diode whose internal resistance is 20J is to supply power to a 100J load from 110V(rms) source pf supply. Calculate (a) peak load current (b) the dc load current (c) the ac load current (d) the percentage regulation from no load to full load.

Solution:

Given a half-wave rectifier circuit R_f=20J, R_L=100J

Given an ac source with rms voltage of 110V, therefore the maximum amplitude of sinusoidal input is given by

$$V_m = \sqrt{2} \times V_{rms} = \sqrt{2} \times 110 = \mathbf{155.56V.}$$

(a) Peak load current : $I_m = \frac{V_m}{R_f + R_L} \Rightarrow I_m = \frac{155.56}{120} = \mathbf{1.29A}$

(b) The dc load current : $I_{dc} = \frac{I_m}{\pi} = \mathbf{0.41A}$

(c) The ac load current : $I_{rms} = \frac{I_m}{2} = \mathbf{0.645A}$

(d) $V_{no\text{-}load}$: $\frac{V_m}{\pi} = \frac{155.56}{\pi} = \mathbf{49.51\ V}$

$V_{full\text{-}load}$: $\frac{V_m}{\pi} - I_{dc} R_f = \mathbf{41.26\ V}$

$$\%\ \text{Regulation} = \frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100 = \mathbf{19.97\%}$$

2. A diode has an internal resistance of 20J and 1000J load from 110V(rms) source pf supply. Calculate (a) the efficiency of rectification (b) the percentage regulation from no load to full load.

Solution:

Given a half-wave rectifier circuit R_f=20J, R_L=1000J

Given an ac source with rms voltage of 110V, therefore the maximum amplitude of sinusoidal input is given by

$$V_m = \sqrt{2} \times V_{rms} = \sqrt{2} \times 110 = 155.56V.$$

(a) % Efficiency (η) = $\frac{40.6}{1+\frac{20}{100}} = \frac{40.6}{1.02}$ = 39.8%.

(b) Peak load current : $I_m = \frac{V_m}{R_f + R_L} = \frac{155.56}{1020}$ = 0.1525 A

= **152.5 mA**

The dc load current : $I_{dc} = \frac{I_m}{\pi}$ = **48.54 mA**

$$V_{no\text{-}load} = \frac{V_m}{\pi} = \frac{155.56}{\pi} = \mathbf{49.51\ V}$$

$$V_{full\text{-}load} = \frac{V_m}{\pi} - I_{dc} R_f = \mathbf{49.51 - (48.54 \times 10^{-3} \times 20)}$$

$$= \mathbf{49.51 - 0.97 = 48.54\ V}$$

$$\%\ \text{Regulation} = \frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100$$

$$= \frac{49.51 - 48.54}{48.54} \times 100 = \mathbf{1.94\ \%}$$

3. An a.c. supply of 230V is applied to a half-wave rectifier circuit through transformer of turns ration 5:1. Assume the diode is an ideal one. The load resistance is 300J.

Find (a) dc output voltage (b) PIV (c) maximum, and (d) average values of power delivered to the load.

Solution: (a) The transformer secondary voltage = 230/5 = 46V.

Maximum value of secondary voltage, $V_m = \sqrt{2} \times 46 = 65V$.

Therefore, dc output voltage, $V_{dc} = \frac{V_m}{\pi} = \frac{65}{\pi}$ = **20.7 V**

(b) PIV of a diode : V_m = **65V**

(c) Maximum value of load current, $I_m = \frac{V_m}{R_L} = \frac{65}{300}$ = **0.217 A**

Therefore, maximum value of power delivered to the load,

$$\mathbf{P_m} = I_m^2 \times R_L = (0.217)^2 \times 300 = \mathbf{14.1W}$$

(d) The average value of load current, $I_{dc} = \frac{V_{dc}}{R_L} = \frac{20.7}{300}$ = **0.069A**

Therefore, average value of power delivered to the load,

$$\mathbf{P_{dc}} = I_{dc}^2 \times R_L = (0.069)^2 \times 300 = \mathbf{1.43W}$$

FULL – WAVE RECTIFIER

A full-wave rectifier converts an ac voltage into a pulsating dc voltage using both half cycles of the applied ac voltage. In order to rectify both the half cycles of ac input, two diodes are used in this circuit. The diodes feed a common load R_L with the help of a center-tap transformer.

A center-tap transformer is the one which produces two sinusoidal waveforms of same magnitude and frequency but out of phase with respect to the ground in the secondary winding of the transformer. The full wave rectifier is shown in the figure below.

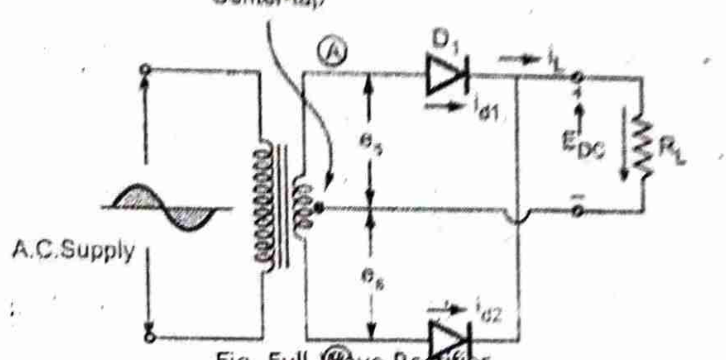


Fig. Full-Wave Rectifier.

The individual diode currents and the load current waveforms are shown in figure below:

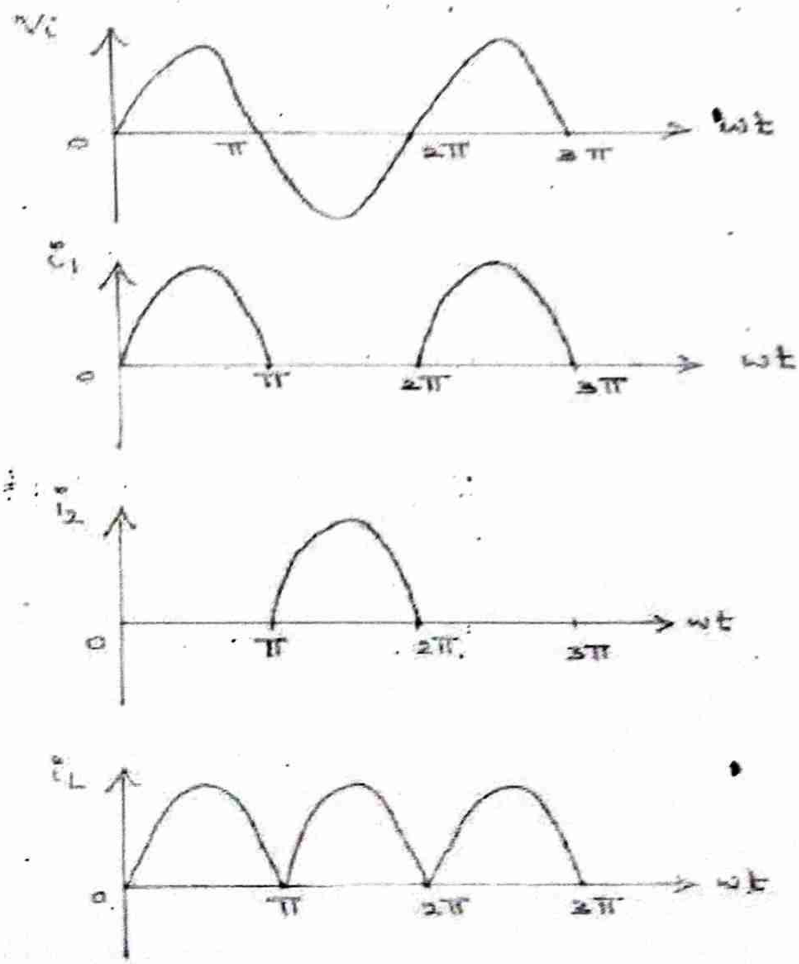


Figure 1.25: Input & Output waveforms of Full wave rectifier