Electronic Devices

Diodes

1. Solids are classified into two categories.

a) Crystalline solids

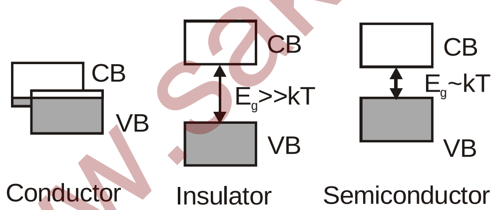
2) Amorphous solids

2. The conductivity of solids can be explained by **Band Theory of solids.**

3. **Band Theory of solids:** A solid is a periodic arrangement of atoms. In case of isolated atom the energy levels are discrete or well separated. For a particular atom in the solid, neighbouring atoms influence the energies of the outer electrons. The discrete energy levels spread into band of energy levels. The highest filled band is called **valance band**. The next higher unfilled band is called **conduction band**. The valance band and conduction band are separated by certain forbidden energy region called **forbidden energy gap** ($E_{.g.}$).

4. The energy bands which are completely filled at 0 K are called valance bands. The bands with higher energies are called conduction bands.

5. Based on band theory of solids, solids are classified as conductors, semiconductors and insulators.



6. Semi-conductors

a) If the forbidden energy gap between the conduction band and valence band is small (about 1 eV) then such substances are called semiconductors.

E.g.: Silicon & Germanium.

b) For silicon forbidden energy gap is 1.1 eV and for germanium 0.72 eV.

c) At absolute zero, semiconductors behave as perfect insulators.

d) Semiconductors are of two types.

a) Intrinsic 2) Extrinsic

7. Hole

a) A hole is an unfilled covalent bond (or) A vacant energy state in the valance band of a semiconductor is called hole.

b) The existence of energy level of a hole can be observed in valence band of a semiconductor.

c) Hole acts like a positive charge but not a particle. Hole drifts in opposite direction to electrons with lesser speed.

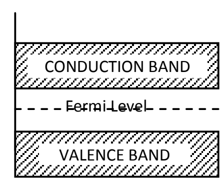
8. Fermi energy: The highest energy level which an electron can occupy at 0 k is called Fermi level. For intrinsic semiconductors this level lies in the middle of the forbidden gap. It can also take as average energy of charge carriers.

9. Intrinsic semiconductors

a) Pure form of Si or Ge crystals is called intrinsic semiconductors (tetravalent).

b) The responsible charge carriers for conduction are both the free electrons and holes.

c) The number of holes and the number of free electrons are equal ($n_e = n_h$) and increase with increase of temperature.



Intrinsic semiconductor

d) Even though the responsible charge carriers are both the free electrons and holes the current contributed by the electrons is more than that of holes because of their higher mobility.

e) Mobility of electrons is nearly twice to that of holes in Germanium and 4 times in silicon.

f) Fermi-energy level lies exactly at the midpoint of the forbidden gap.

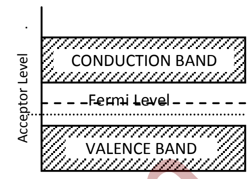
10. Extrinsic semiconductors

a) The conductivity of intrinsic semiconductor is relatively less. To increase their conductivity pure semiconductors are doped with trivalent or pentavalent substances.

b) **Doping:** Adding of selected impurities to a semiconductor to increase its conductivity is called doping.

c) The doped semiconductors are called as extrinsic semiconductors. They are of two types. i) p-type, ii) n-type.

11. p-type semiconductor



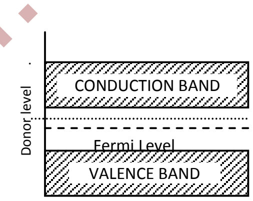
p-type semiconductor

a) When a trivalent substance (III group elements) like Boron, Aluminium, Gallium, Indium etc., are added in sufficient quantities (1 in 10^6 or less) to the pure form of Si or Ge crystal then it is said to be p-type.

b) In p-type semiconductor, holes are majority carriers and electrons are minority carriers ($n_h > n_e$)

c) The Fermi-energy level lies nearer to the valence band.

d) It is electrically neutral.



n-type semiconductor

e) The energy level formed slightly above (about 0.01 eV) the valence band due to acceptor impurities is called acceptor energy level.

12. n-type semiconductor

a) When a pentavalent substance (V group elements) like Phosphorous, Arsenic, Antimony etc., are added in sufficient quantities to the pure form of Si or Ge crystal then it is said to be n-type.

b) In n-type semiconductor, electrons are majority carriers and holes are minority carriers. ($n_e > n_h$).

c) The Fermi-energy level in nearer to the conduction band.

d) It is electrically neutral.

e) The energy level formed slightly below (about 0.01 eV) the conduction band due to donor impurities is called donor energy level.

1) Conductivity of n-type > p-type > intrinsic.

2) With the increase of temperature Fermi level moves down.

13. p-n junction: When a semi conducting material such as silicon or germanium is doped with impurity in such a way that one side has a large number of acceptor impurities and the other side has a large number of donor impurities. The resulting semiconductor is called p-n junction.

14. p-n junction diode

a) A p-n junction diode cannot be obtained by simple contact of p-type and n-type semiconductor.

b) Near the junction, the free electrons from n-region migrate towards p-region and the holes in p-region migrate towards n-region. This process is known as diffusion. This diffusion is due to concentration gradient.

c) Due to diffusion, positive ions are left over in n-region and negative ions are left over in p-region, near the junction. These ions are immobile.

d) Due to the immobile ions on either side of the junction an internal electric field is formed at the junction, which is directed from n to p.

e) The no charge carrier region formed at p-n junction due to the combination of electrons and holes is called **depletion layer**.

f) The thickness of the depletion layer is of the order of 10^{-6} m.

g) When the depletion layer is sufficient by built up, it prevents the electrons diffusion from n to p side and hole diffusion from p to n side i.e., it acts as a barrier.

h) The potential difference across the barrier which is set up to prevent diffusion of charge carriers through the junction is called **potential barrier** or **contact potential**.

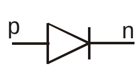
i) The potential barrier for silicon is 0.7 volts and for germanium is 0.3 volts.

j) The potential barrier value lies in between 0.1 to 0.7 volts, which depends on the nature of semiconductor, doping concentration and temperature of the junction.

k) It can be presumed to be equivalent to a condenser in which the depletion layer acts as a dielectric.

l) p-n junction diode can be used as rectifiers, detectors.

m) In a circuit p-n junction diode is represented as. Here arrow mark represents the direction of current in forward bias. It represents 'p' side.



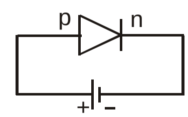
Drift Current

n) Due to thermal collisions, electron-hole pairs are created in the depletion region. The electron is quickly pushed by the electric field towards the n-side and the hole towards the p-side. As electron-hole pairs are continuously created in the depletion region, there is a regular flow of electrons towards the n-side and of holes towards the p-side. This makes a current from the n-side to the p-side. This current is called the drift current.

a) **Diffusion current:** When a p-n junction is formed, because of the concentration difference, holes try to diffuse from the p-side to n-side. Similarly, electrons try to diffuse from n-side to p-side. This diffusion results in an electric current from the p-side to the n-side known as diffusion current.

v) The drift current and the diffusion current are in opposite directions. In unbiased junction, in steady state, the diffusion current equals the drift current in magnitude there is no net transfer of charge at any cross-section.

15. Forward Bias



a) In a p-n junction diode, if p-region is connected to +ve terminal (relatively higher potential) of the battery and n-region is connected to –ve terminal (relatively lower potential) of the battery then it is said to be forward biased.

b) In forward biased condition, the width of depletion layer and barrier potential decrease.

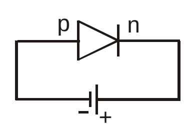
c) It is a low resistance connection.

d) The resistance of an ideal diode in forward biased condition is zero.

e) In forward biased condition, the flow of current is mainly due to the diffusion of electrons.

f) The direction of current is from p to n.

16. Reverse Bias



a) In a p-n junction diode, if p-region is connected to –ve terminal (relatively low potential) of the battery and n-region is connected to the +ve terminal (relatively high potential) of the battery then it is said to be reverse biased.

b) In reverse biased condition, the width of the depletion layer and barrier potential increase.

c) It is a high resistance connection.

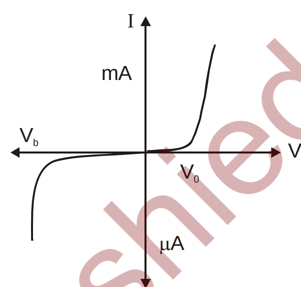
d) The resistance of an ideal diode in reverse bias condition is infinity.

e) In reverse biased condition, the flow of current is mainly due to the drift of charges.

f) The direction of current in it is from n to p.

i-v relation of diode is $i = i_0[e^{\frac{qv}{KT}} - 1]$ where i_0 is reverse saturation current, KT is thermal energy and q is charge of electron. In forward bias $i = i_0 e^{\frac{qv}{KT}}$ in reverse bias $i = -i_0$

I-V characteristics



V_b-break down voltage
V_0-barrier potential

Diode is unidirectional. It allows current in forward bias when applied potential is greater than the barrier potential.

17. Rectifier

a) The conversion of A.C. voltage to D.C. voltage is called **rectification**.

b) A p-n junction diode is used as a rectifier.

c) When a single diode is used as a rectifier, the rectification of only one half of the A.C. wave form takes place. Such a rectification is called **half wave rectification**.

18. Efficiency of half wave rectifier

a) The ratio of D.C. power output to the applied input A.C. power is known as rectifier efficiency.

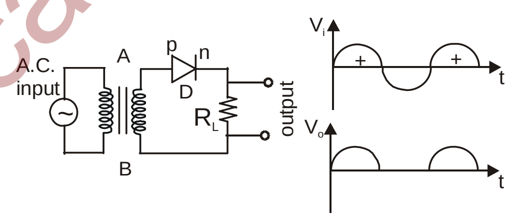
b) Rectifier efficiency $\eta = \frac{P_{dc}}{P_{ac}} = \frac{0.406R_L}{R_L + r_f}$ where R_L - load resistance, r_f - diode resistance.

19. In half wave rectification, a maximum of 40.6% of A.C. power is converted into D.C. power.

In a half wave rectifier, if input frequency is n Hz A.C., then the output pulse frequency is n Hz D.C.

a) Maximum current $i_m = \frac{V_m}{r_f + R_L}$ where V_m = maximum voltage, r_f = internal resistance of the diode, R_L = load resistance.

b) Average current $I_{dc} = \frac{I_m}{\pi}$

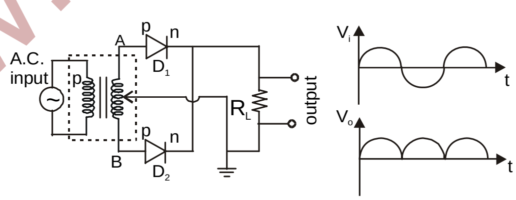


c) rms current $i_{rms} = \frac{i_m}{\sqrt{2}}$.

d) a.c power input $= i_{rms}^2 \times (r_f + R_L)$

e) d.c power output $P_{dc} = (I_{d3})^2 x R_L$

20. When two diodes are used, then the rectification of both halves of the alternating voltage or current can be obtained. Such a rectification is called **full wave rectification**.



a) In a full wave rectifier, if input frequency is n Hz A.C., then the output pulse frequency is 2n Hz pulsated D.C

21. Filter circuit: The output current either from half wave rectifier or full wave rectifier, though unidirectional is not steady. It also contains A.C. components which are undesirable and are to be removed by using filter circuit. Filter circuit is a device which removes the A.C. component of rectifier output and allows the D.C. component to reach the load.

22. Efficiency of full wave rectifier

a) The ratio of D.C. power output to the applied input A.C. power is known as rectifier efficiency.

b) Full wave rectifier efficiency $\eta = \frac{P_{dc}}{P_{ac}} = \frac{0.812 R_L}{r_f + R_L}$ where r_f - diode resistance, R_L - load resistance.

23. In full wave rectifier a maximum of 81.2% of A.C. power is converted into D.C. power.

a) Maximum current $I_m = \frac{V_m}{r_f + R_L}$ where V_m = maximum voltage, r_f = internal resistance of the diode, R_L = load resistance.

b) Average current $i_{av} = \frac{2I_m}{\pi}$ where I_m = maximum current

c) rms current $i_{rms} = \frac{I_m}{\sqrt{2}}$.

d) A.C. power input $= i_{rms}^2 x (R_L + r_f)$;

e) D.C. power output $P_{dc} = (I_{d3)})^2 x R_L$

24. Advantages of Semiconductor diodes

a) p-n junction diodes are minute (very small in size). Therefore these are used in microcircuits.

b) As they are solid state devices, no evacuation is needed as in vacuum tubes.

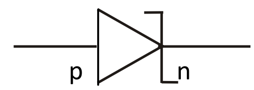
c) They are also quite strong and sturdy.

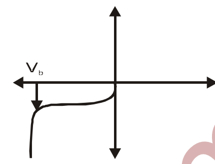
d) Usually they have long life.

e) There is no filament heating and consequent power loss.

f) These can be prepared to function over wide voltage ranges and to give very large rectified currents.

25. Zener diode





V_b-break down voltage

a) It is a heavily doped p-n junction diode which is operated in the breakdown region in reverse bias mode.

b) Zener diode has a sharp breakdown voltage in the reverse bias because of heavy doping. This voltage is called Zener Voltage (V_Z).

c) Because of heavy doping width of the depletion layer decreases, the electric intensity in the depletion layer increases Zener breakdown is pulling the electrons from valence bonds by the action of this strong electric field.

d) In forward bias, Zener diode act like an ordinary p-n junction diode.

e) Zener diode is used as a voltage regulator.

f) Output voltage (V_O)=Zener voltage (V_Z)

g) Current through load resistance (I_L) $=\frac{V_Z}{R_L}$.

h) Voltage across series resistance (V) =input voltage – zener voltage. $V=V_i-V_Z$

i) Current through series resistance (R) is $I=\frac{V}{R}=\frac{V_i-V_Z}{R}$.

j) Current through Zener diode (I_Z) $=I-I_L$.

k) Series resistance absorbs voltage fluctuations and Zener diode absorbs current fluctuations.

l) The maximum reverse bias potential that can be applied before commencement of Zener region is called the Peak Inverse Voltage [PIV].