PH8252 - PHYSICS FOR INFORMATION SCIENCE

UNIT-II

SEMICONDUCTOR PHYSICS

Part A

1. What is a semiconductor?

A semiconductor is a material which behaves like an insulator at 0K and acts as conductor at temperature other than 0K. Its electrical resistivity lies in between a conductor and an insulator.

Where 0K is Absolute Zero Degree Kelvin. (0^0K)

2. State the properties of a semiconductor.

- In semiconductors, both the electron and holes are charge carriers.
- The conductivity increases due to temperature and impurities.
- At 0K, they behave as insulators.
- They possess crystalline structure.
- They have negative temperature co-efficient of resistance.

3. What is meant by intrinsic and extrinsic semi-conductors? Give examples.

Extremely pure semiconductors without any impurities are known as intrinsic semiconductors.

Example: Germanium and Silicon.

Semiconductor which contains impurity atoms due to doping, is known as extrinsic semiconductors or impure semiconductors.

Example: Phosphorus, arsenic or antimony added to either germanium or silicon gives n- type semi-conductors while aluminium, gallium or indium added results in p-type semiconductors.

4. What are elemental semiconductors? Give two examples:

Pure semiconductor elements from fourth column are called intrinsic semiconductors. When this is doped with pentavalent (or) trivalent impurity elements, we get n-type or p-type extrinsic semiconductors. These intrinsic and extrinsic semiconductors are known as elemental semiconductors.

Example: Germanium and Silicon.

5. What are compound semiconductors? Give two examples.

Semiconductors formed by the combination of fifth and third column or sixth and second column elements are called compound semiconductors.

Example: GA As and In P for III – V compounds.

MgO and CdS for II - VI compounds.

6. State law of mass action in semiconductor.

For any given semiconductors, the product of electron and whole concentration remains constant at a given temperature and is equal to the square of the intrinsic carrier concentration.

$$n \times p = n_i^{-2}$$

7. What are n-type and p-type semiconductors? Give examples:

When an intrinsic semiconductor is doped with pentavalent impurity, we get n-type semiconductors. Principal charge carriers is electrons.

When an intrinsic semiconductor is doped with trivalent impurity, we get p-type semiconductors. Principal charge carriers is holes.

Example: Phosphorous, arsenic or antimony added to either germanium or silicon gives n-type semiconductors while aluminium, gallium or indium added results in p-type semiconductors.

8. At 0K, when does an intrinsic semiconductor behave like an insulator? Why?

At absolute zero, the valence band of an intrinsic semiconductor is completely filled and the conduction band that is separated by a distance E_g from the valence band is empty. For this reason, at absolute zero, an intrinsic semiconductor behaves as an insulator.

9. Differentiate between intrinsic and extrinsic semiconductor.

Intrinsic Semiconductors	Extrinsic Semiconductor
1. Pure Semiconductors	Impure semiconductors. When doped with pentavalent impurities it is n-type. When Doped with trivalent impurities it is p-type.
2. Both electrons and holes are charge carriers.	Electrons are majority carriers in n-type. Holes are majority carriers in p-type.
3. Charge carriers are generated due to breaking of covalent bonds.	Charge carriers are generated due to ionization of dopant.
4. Fermi energy is exactly at the middle of Forbidden energy gap.	Fermi energy is just below conduction band in n-type. Fermi energy is just above valence band in p-type.

10. What is meant by doping?

The process of adding impurities into an intrinsic semiconductor is known as 'doping'.

11. Why do we prefer extrinsic semiconductors than intrinsic semiconductors? Give reason.

Extrinsic semiconductors have high electrical conductivity. Which depends on the number of dopant atoms and have high operating temperature. But in an intrinsic semiconductor, the electrical conductivity is very small and is not a constant at different temperatures.

12. Define operating temperature of a semiconductor.

The operating temperature of a semiconductor is defined as the maximum temperature upto which extrinsic behaviour is existed. For example, silicon has the operating temperature of 200^{0}c so that the silicon transistors or diodes can be operated safely with effect of doped impurities upto 200^{0}c.

13. Distinguish between indirect and direct band gap semiconductors.

Indirect band gap	**Direct band gap**
1.They are made of a single element like Ge, Si, etc. Germanium, Silicon.	They are made of compound elements like GA As, In, etc…,
2. They are called elemental semiconductors	They are called as compound semiconductors.
3. The electron from the conduction band Recombine with the holes in the valence Band indirectly through traps.	The electrons from the conduction band Recombine with the holes in the valence band directly.
4. Heat is evolved during recombination.	Photons are emitted during recombination.
5. Life time is more	Life time is less.
6. Current amplification is more.	Current amplification is less.
7. They are used to fabricate rectifier, diodes and transistor.	They are used to fabricate LED and LASER diodes.

14. What is a covalent bond?

Covalent bond is the strong classical electron pair bond. It acts between natural atoms. The covalent bond is formed with two electrons, one from each atom being shared by both the atoms.

Example: Germanium, silicon, Diamond has covalent bond.

15. What happens when the temperature increases in the case of semiconductor and Conductor?

In the case of semiconductor, conductivity increases with increase in temperature.

In the case of conductors, conductivity decreases with increase in temperature.

16. What is meant by donor energy level?

A pentavalent impurity when doped with an intrinsic semiconductor donates one electron which produces an energy level called donor energy level.

17. What is meant by acceptor energy level?

A trivalent impurity when doped with an intrinsic semiconductor accepts one electron which produces an energy level called acceptor energy.

18. What are donors and acceptors?

The donors are the doped pentavalent impurity atoms like p, As and Sb in silicon or germanium donating an electron from its atom to silicon or germanium crystal.

The acceptors are the doped trivalent impurity atoms like Al, In and Ga in silicon or germanium accepting an electron from silicon or Germanium atom.

19. Distinguish between N-type and P-type semiconductors.

N – type semiconductors	**P – type semiconductors**
It is obtained by doping intrinsic semiconductors with pentavalent impurity.	It is obtained by doping intrinsic semiconductors with trivalent impurity.
2. Electrons are majority charge carrier and Holes are minority carriers.	Holes are majority charge carrier and Electrons are minority carriers.
3. Donor level lies just below the conduction Band.	Acceptor level lies just above the valence band.

20. Compared with Germanium, silicon is widely used to manufacture the elemental device. Why?

Silicon is an indirect band gap semiconductor for which the life time of the charge carrier and current amplification is more. Also, the electrical conductivity due to doping increases in silicon when compared with Germanium. Hence, silicon is widely used to manufacture elemental devices.

21. What is Fermi level in a semiconductor?

Fermi level in a semiconductor is the energy level situated in the band gap of the semiconductor. It is exactly located in the middle of the band gap in the case of an intrinsic semiconductor at 0K.

22. Define Hall Effect and Hall Voltage?

When a piece of material carrying current is placed in a transverse magnetic field, an electric field is produced inside the conductor in a direction normal to both the current and the magnetic field. This phenomenon is called Hall Effect and the generated voltage is known as Hall voltage.

23. Mention the application of Hall Effect.

- Determination of type of semiconductor.
- Calculation of carrier concentration.
- Determination of mobility.
- Measurement of magnetic flux density.

24. How will you distinguish N-type and P-type semiconductors using Hall Effect?

For N-type, the Hall coefficient is negative and for p-type, the Hall co-efficient is positive. Thus, from the direction of Hall voltage developed, the semiconductors can be distinguished.

25. How the Fermi energies vary with doping density?

N-type: When the temperature is increased, some of the electrons are shifted from donor energy level to the conduction band and hence the Fermi energy level is shifted down.

P-type: When the temperature is increased, some of the electrons in the valence band go to acceptor energy levels and hence the Fermi level is shifted in upward direction.

26. Why do we prefer Si for transistors and GA As for laser diodes?

Si is an indirect band gap semiconductor for which the life time and current amplification is more. Hence it is preferred for transistors.

GA As is a direct band gap semiconductor in which electrons and holes recombine directly to produce photons and hence it is preferred for laser diodes.

27. Define: drift transport.

When an electric field is applied to a semiconductor, the electrons are attracted to the positive terminal and the holes are attracted to the negative terminal. The charge carriers are forced to move in a particular direction due to the field. This is known as drift motion and the net movement of charge carriers is termed as drift transport.

28. Define diffusion transport.

When an electric field is applied, in addition to the drift motion, the charge carriers also move by diffusion at the places. The charge carriers move from the regions of higher concentration to the region of lower concentration in order to attain uniform distribution. This transport is called diffusion transport.

29. What is ohmic contact?

An ohmic contact is a non-rectifying electrical junction. The junction between two conductors which has a linear current – voltage curve that satisfy ohm's law is known as ohmic contact.

30. What is a Schottky diode?

Schottky diode is a metal – semiconductor junction diode formed between a metal and moderately doped n-type semiconductor material.

31. Explain the concept of hole in semiconductor.

In intrinsic semiconductor, the charge carriers are created due to the breaking of covalent bonds. During the breaking, an electron moves to the conduction band leaving behind a vacant site called hole. These holes will move in the direction opposite to that of the electron.

32. Compare Schottky diode and p-n junction diode.

(i) The current in a conventional p-n junction diode is controlled by the diffusion of minority carriers whereas the current in the Schottky diode results from the flow of majority carriers over the potential barrier at the metal – semiconductor junction.

(ii) The reverse saturation current for a Schottky diode is larger than that of a p-n junction diode.

(iii) The Schottky diode has a smaller turn-on voltage and shorter switching time than the p-n junction diode.

33. Define impurity range in N-type semiconductors.

The impurity range is due to the transfer of electrons from donor energy levels to conduction band. Here, the electron concentration in the conduction band steadily increases due to ionization of donor atoms.

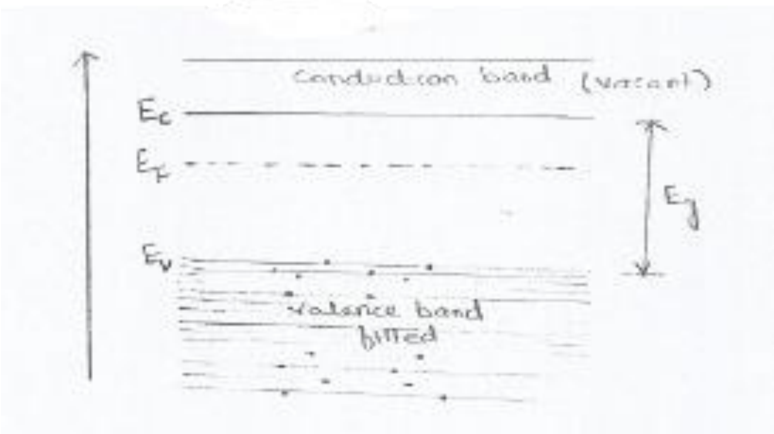
34. Define exhaustion range in N-type semiconductor?

When all the electrons are transferred from donor energy level to conduction band, the electron concentration remains constant over certain temperature and is called exhaustion range.

35. Define intrinsic range in N-type semiconductors.

In intrinsic range, the N-type semiconductor practically behaves like an intrinsic semiconductor. If the temperature is increased, the electron concentration in the conduction band increases rapidly due to shifting of electrons from valence band to conduction band.

36. Draw the energy band diagram for an intrinsic semiconductor with its parameters.



37. A silicon plate of thickness 1mm, breadth 10mm and length 100mm is placed in a magnetic field of o.5 wb/m^2 acting perpendicular to its thickness. If 10^{-2} A current flows along its length, calculate the Hall voltage developed if the Hall coefficient is 3.66 x 10^{-4} m^3 / coulomb.

Given:

t = 1mm =1 x 10^{-3} m

b = 10mm = 10 x 10^{-3} m

L = 100m = 100 x 10^{-3}m

B = 0.5 wb/m^2

I = 10^{-2} A

R_h = 3.66 x 10^{-4} m^3/ coulomb

Formula: RH = $\frac{V_H t}{IB}$

Solution:

$\therefore\ V_H = \frac{R_H IB}{t}$

$= \frac{3.66 \text{ x } 10^{-4} \text{ x} 10^{-2} \text{x } 0.5}{1 \text{ x } 10^{-3}} = 1.83 \text{ x } 10^{-3}$

V_H = 1.83mV

38. In an N-type germanium sample has a donor density of 10^{21}/m^3. It is arranged in a Hall Experiment having B = 0.5 wb/m^2 and J = 500 Am^{-2}. Find the Hall voltage if the sample is 3mm thick.

Given

N_d = 10^{21}/m^3 n $\approx N_d$

B = 0.5T

J = 500 A/m^2

b = 3mm = 3 x 10^{-3}m.

V_H =?

Formula,

$$V_H = \frac{R_H IB}{t} = \frac{IB}{net} \qquad \therefore \; R_H = \frac{1}{ne}$$

$$= \frac{BJA}{net} = \frac{BJbt}{net} \qquad \therefore \; I = JA \qquad dA = bt$$

Solution:

$$V_H = \frac{BJb}{ne} = \frac{0.5 \text{ x } 500 \text{ x } 3 \; x \; 10^{-3}}{10^{21} \text{ x } 1.6 \text{ x } 10^{-19}} = 4.7 \; x \; 10^{-3} \; v$$

39. Determine the density of donor atoms which have to be added to an intrinsic Semiconductor to produce an n-type semiconductor of conductivity 5 mho/cm. Given the mobility of electrons is 3850 m^2 v^{-1} s^{-1}.

Given,

μ_e = 3850 $m^2v^{-1}s^{-1}$

σ = 5 ohm^{-1} cm^{-1}

= 5 x 10^2 ohm^{-1} m^{-1}

N_d =?

Formula,

σ = ne μ_e

= $N_d \; e \; \mu_e$

$\therefore$ $N_d = \frac{\sigma}{e\mu_e}$

Solution:

$$N_d = \frac{5 \text{ x } 10^2}{1.6 \text{ x } 10^{-19}} \text{ x } 3850 = 8.11 \text{ x } 10^{17} / \text{m}^3$$

40. The intrinsic comer density at room temperature in Ge is 2.37 x 10^{19}/m^3. If the Electron and hole mobilities are 0.38 and 0.18 $m^2v^{-1}s^{-1}$ respectively, calculate the resistivity.

Given,

$N_i = 2.37 \times 10^{19}/m^3$.

$\mu_e = 0.38\ m^2v^{-1}\ s^{-1}$

$\mu_h = 0.18\ m^2v^{-1}s^{-1}$

$\rho = ?$

Formula,

$\sigma = n_i e(\mu_e + \mu_h)$

Solution:

$$\therefore \rho = \frac{1}{\sigma}$$

$$= \frac{1}{n_i e\,(\mu_e + \mu_h)}$$

$$= \frac{1}{2.37 \times 10^{19}} \times 1.6 \times 10^{-19}(0.38 + 0.18)$$

$$\rho = 0.4709\ ohm\ m.$$