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ASSIGNMENT-3

UNIT-3

Q1- What is fermi level?

Ans- The fermi level represents the energy level at which the probability of finding electron is 50% at absolute zero temperature.
It is for understanding electron behaviour in materials, particularly in semi conductors aiding in device design & analysis

Q2- Write 4 materials from III group?

Ans (i) Aluminium - (Al)
(ii) Gallium - (Ga)
(iii) Indium - (In)
(iv) Thallium - (Tl)

Q3- State mass action law?

Ans- In a semiconductor (intrinsic / extrinsic) under thermal equilibrium the product of electrons and holes is always constant and is equal to the square of intrinsic conc.
The law is mainly used for extrinsic semiconductor to calculate carrier concentration

Q4- Describe P-type & n type semiconductor in terms of its materials resistivity conductivity and mobility

Ans- • P-type - Semiconductors are doped with acceptor impurities like boron forming holes. They exhibit higher resistivity, lower conductivity and lower electron mobility.

• n-Type - Semiconductors are doped with donor impurities like phosphorous introducing excess electrons. They have lower resistivity, higher conductivity and higher electron mobility.

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Q5 - Write the electron neutrality equation?

Ans - $n + p = n_i^2$

where, $n \rightarrow$ concentration of free electrons

$p \rightarrow$ concentration of holes

$n_i \rightarrow$ Intrinsic carrier concentration.

PART-B

Q1 - Write the difference b/w direct band gap and indirect band gap.

Ans -

DIRECT BAND GAP	INDIRECT BAND GAP
• Efficiently emit or absorb photons due to direct transition b/w energy bands.	• Have lower efficiency due to the involvement of momentum-changing process
• Typically exhibit stronger optical properties, making them suitable for opto-electronic devices like LED's and lasers	• Less efficient in these devices
• Electron transition occurs with minimal change in momentum.	• Involve momentum changing processes like phonon scattering due to different momentum state of conduction ~~&~~ valence bands.
• Typically have shorter carriers lifetime due to the efficient recombination of electron hole pairs.	• Carrier lifetime may be longer due to slower recombination rates.
• Most of energy is dissipated in form of light.	• Most of energy is dissipated in form of heat.

• Favour exciton formation where electron-hole pair interact strongly due to their spatial proximity	• Have weaker excitonic effects.
• Common direct band gap materials include III-V compounds like GaAs, InP, and GaN as well as some II-VI compounds.	• Indirect Band gap materials include Si, Ge and III-V and II-VI compounds
• Find application in opto-electronic devices such as LED, lasers and photodetectors due to their efficient photon emission & absorption.	• Used in electronic devices like transistors & solar cells, where direct band gap material are less effective.

Q2- An intrinsic silicon with $n_i = 1.5 \times 10^{10}/cm^3$ is doped with boron acceptor impurity $N_A = 2 \times 10^{22}/cm^3$. Determine the type of extrinsic material. Also find the number of holes & electrons per cm^3.

Ans- $n_i = 1.5 \times 10^{10}/cm^3$

$N_A = 2 \times 10^{22}/cm^3$

If

$N_A > n_i \rightarrow$ The material is p-type

$N_A < n_i \rightarrow$ The material is n-type

$p = N_A - n_i$

$n = n_i$

$p = 2 \times 10^{22} - 1.5 \times 10^{10} = 1.99 \times 10^{22}/cm^3$

$n = 1.5 \times 10^{10}/cm^3$

So, no. of holes/cm^3 = $1.99 \times 10^{22}/cm^3$

no. of electrons/cm^3 = $n = 1.5 \times 10^{10}$

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Q3- Explain mobility, drift current, diffusion current.

Ans- (i) Mobility - Mobility indicates how quick the e^- or the hole will be moving from one place to another place.

$$\mu = \frac{\text{drift velocity}}{\text{field intensity}} = \frac{v}{E_0} \quad \frac{m/sec}{volt/m} = m^2/Vsec$$

mobility of e^- > mobility of holes

→ so e^- contribute more current as compared to holes.

→ mobility of charge carrier always decreases with increase in temp. because atoms in material will vibrate, due to this thermal vibration mobility of charge carriers decrease

$$\boxed{\mu \propto T^{-m}}$$

(ii) drift current - It is the flow of current through material or device under the influence of applied voltage or due to E.

(iii) diffusion current - Diffussion is defined as the migration of charge carriers from high conc. to low conc. due to unequal distribution of charge carriers.

Diffusion current flows only in semiconductors.

PART-C

Q1- A pure SC (Ge) is doped with donor impurities to the extent of 1:10^7. Calculate a) Donor concentration

b) electron and hole concentration

c) conductivity and resistivity of doped SC

d) How many times the conductivity is increase in the SC due to doping.

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Ans- (a) DONOR CONCENTRATION - Given that the pure semiconductor (Ge) is doped with donor impurities to the extent 1:10^7 - this means that for every Ge atom, there is one donor atom. Therefore, the donor concentration is equal to the doping concentration - $1 \times 10^7 /cm^3$.

(d)

(b) ELECTRON & HOLE CONCENTRATION - In a n-type semiconductor we are doped with donor impurities the majority charge carriers are e^-'s and the minority charge carriers are holes. Since Ge is doped with donor impurities we can assume that all donor atoms ionize & contribute one extra electron to the conduction band for each doping atom.

$$n_i^2 = np$$

$$\text{electron conc} = \text{Donor conc.} = 1 \times 10^7/cm^2$$

$$\text{Hole conc.} = n_i^2 \times np$$

$$p = \frac{n_i^2}{n} = \frac{(2.4 \times 10^3)^2}{1 \times 10^7}$$

$$p \simeq 5.76 \times 10^8/cm^3$$

Q2-

Ans-

(c) CONDUCTIVITY AND RESISTIVITY - Conductivity can be calculated:

$$\sigma = q . \mu_n . n$$

q = elementary charge

μ_n = electron mobility

n = electron concentration,

Resistivity can be calculated ~~[illegible]~~ as reciprocal of conductivity

$$\left(\rho = \frac{1}{\sigma}\right)$$

$$\sigma = q . \mu_n . n = (1.6 \times 10^{-19}) \times \text{mobility} \times 1 \times 10^7$$

$$\text{Mobility} \simeq 0.39 cm^2/s$$

$$\sigma = 1.6 \times 10^{-19} \times 0.39 \times 1 \times 10^7 \ s/cm$$

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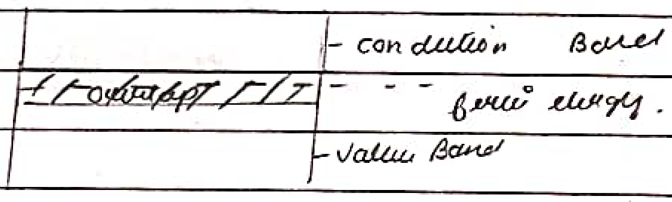
(d) INCREASING CONDUCTIVITY DUE TO DOPING - The increase in conductivity due to doping can be calculated by comparing the conductivity of doped ~~intrinsic~~ semiconductor to the conductivity of intrinsic semiconductor. To find the increase in conductivity compare the conductivity of the doped sc to the intrinsic conductivity of pure Ge.

Q2- Explain the properties of the conductivity semi-conductor & insulator with the help of energy band diagrams.

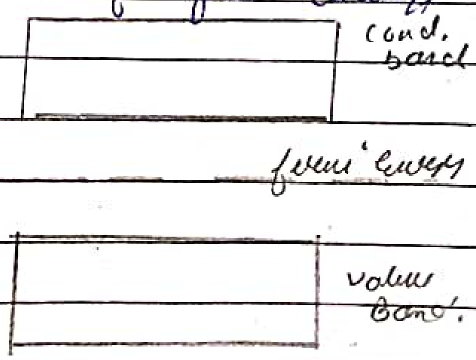
Ans- CONDUCTOR - • high conductivity due to large number of free electrons that can be move easily in response to an electric field.

- The value & conductor bands, overlap, allowing electrons to move freely.
- low resistance due to flow of electric current
- Eg: Cu, Ag, Au.



INSULATOR - • very low conductivity due to lack of free charge carriers.

- wide energy gap b/w the valence and conduction bands, making it difficult for electrons to move.
- High resistance
- Eg: Glass, rubber, Plastic etc.

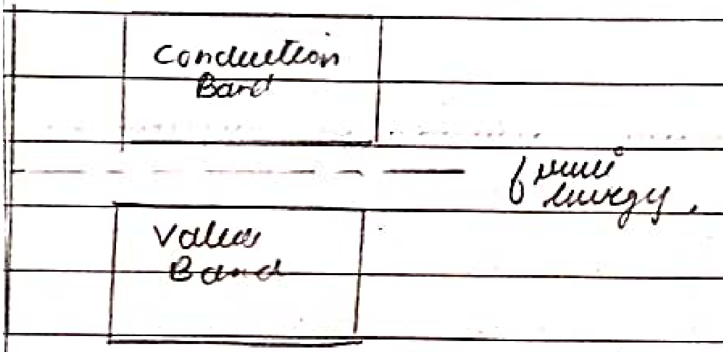


SEMICONDUCTOR - • Intermediate conductivity between conductors & insulators. conductivity can be modulated by doping and temperature.

• Energy gap between the valence and conduction bands. At room temperature some electrons are promoted to the conduction band, allowing for some current to flow.

• Moderate resistance compared to conductors & insulators

◦ Eg : Si, Ge and various compound semiconductors



Derive expression for current density inside a conductor extend the expression for semiconductors.

In a conductor, the current density (J) is directly proportional to the electric field (E), and conductivity (σ), and inversely proportional to resistivity

$$J = \sigma E \quad A/cm^2$$

where, σ is conductivity of material and E is electric field.

In terms of resistivity

$$J = \frac{E}{\rho}$$

For semiconductors, current density (J) is given by sum of drift current density (Jd) and the diffusion current density (Jn) which is expressed as:

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$J = J_d + J_n$

The drift current density is proportional to charge carrier mobility (μ) carrier concentration (n) and electric field (E)

$$J_d = q \cdot n \cdot \mu \cdot E$$

∴ where, q is charge of carrier

The diffusion current density is $\propto$ (proportional) to gradient of carrier concentration (∇n) & diffusion co-efficient (D)

$$J_n = q \cdot D \cdot \nabla n$$

Combining both expression for J_d and J_n we get the total current density in semiconductor.