Anna University Solved Problems

Unit - 2: Semiconductor Physics

1. **Find the resistance of an intrinsic germanium rod 1cm long, 1mm wide and 1mm thick at 300K. For germanium n_i =2.5 x 10^{19} m^{-3};μ_e = 0.39 $m^2V^{-1}S^{-1}$ and μ_h = 0.19 $m^2V^{-1}S^{-1}$ (*DECEMBER 2014*)**

Given data(s): (i) Intrinsic carrier concentration (n_i) =2.5 x 10^{19} m^{-3}
(ii) Electron mobility (μ_e) = 0.39 $m^2V^{-1}S^{-1}$
(iii) Hole mobility (μ_h) = 0.19 $m^2V^{-1}S^{-1}$
(iv) Length of the rod (l) = 1 cm = 1 x 10^{-2}m
(v) Area = breadth x thickness = (1x10^{-3})x(1x10^{-3}) = 1 x 10^{-6}m
(vi) charge of electron (e) = 1.6 x 10^{-19} C.

Formula(s): (i) Electrical conductivity of an intrinsic semiconductor $\sigma_i = n_i e(\mu_e + \mu_h)$

(ii) $R = \frac{\rho l}{A} (or) R = \frac{l}{\sigma A}$

Calculation(s): (i) $\sigma_i = 2.5 \times 10^{19} \times 1.6 \times 10^{-19} \times (0.39 + 0.19) = 2.32 \Omega^{-1} m^{-1}$ m^{-3}

(ii) $R = \frac{1 \times 10^{-2}}{2.32 \times 1 \times 10^{-6}} = 4310 \Omega$

Answer(s):
(i) Electrical conductivity (σ) = 2.32 Ω^{-1} m^{-1}
(ii) Resistance (R) = 4310 Ω.

2. **A silicon material is uniformly doped with phosphorus atoms at a concentration of 2 x 10^{-19} m^{-3}. The Mobilities of electrons and holes are 0.05 and 0.12 m^2V^{-1} S^{-1} respectively. N_i = 1.5 x 10^{16} m^3. Find the electron and hole concentration and its electrical conductivity. (*June 2014*).**

Given data(s):
Carrier concentration (n_i) = 1.5 x 10^{16} m^3.
Donor concentration (N_D) = 2 x 10^{19} m^3.

Formula(s): $p = \frac{n_i^2}{N_D}$

$n = N_D$

$\sigma = eN_D\mu_e$

Calculations:

Hole concentration $p = \frac{n_i^2}{N_D} = \frac{(1.5 \times 10^{16})^2}{2 \times 10^{19}} = 1.125 \times 10^{13} m^{-3}$

Electron concentration n=N_D = 2 x 10^{19} m^{-3}

Electrical conductivity $\sigma = 1.6 \times 10^{-19} \times 2 \times 10^{19} \times 0.12$

σ = 0.384 σ^{-1} m^{-1}

Result(s)

Hole concentration = 1.125 x 10^{13} m^{-3}
Electron concentration n= 2 x 10^{19} m^{-3}
Electrical conductivity σ = 0.384 σ^{-1} m^{-1}

3. **The hall coefficient of a specimen of a doped silicon is found to be 3.66 x 10^{-4} m^3/C. The resistivity of the specimen is 8.93 x 10^{-3} Ω m. Find the mobility and density of the charge carriers (*April 2015*).**

Given data (s):
Hall coefficient (R_H) = 3.66 x 10^{-4} m^3/C
Resistivity (ρ) =8.93 x 10^{-3} Ω m

Formula (s):

Density of charge carriers $n = \frac{1}{R_H e}$ m^{-3}

Mobility $\mu_e = \frac{1}{\rho e n_i} (or) \mu_e = \frac{R_H}{\rho}$

***Calculation(s)*:**

$$n_e = \frac{1}{3.66\times10^{-4}\times1.6\times10^{-19}} = 1.708\times10^{22}\,m^{-3}$$

$$\mu_e = \frac{3.66\times10^{-4}}{8.93\times10^{-3}} = 0.041 m^2V^{-1}S^{-1}$$

Results:

Carrier concentration (n_e) = 1.708 x 10^{22} m^{-3}

Mobility (μ_e) = 0.041 m^2 V^{-1} S^{-1}.

4. **For an intrinsic semiconductor with a band gap of 0.7 eV, determine the position of E_F at T = 300 K if m_h^* = $6m_e^*$ (*Nov. 2003*).**

Given data (s):
E_g = 0.7 eV (or) 1.12 x 10^{-19} J (to convert eV to J multiply by 1.6 x 10^{-19}C)
T = 300 K

$$\frac{m_h^*}{m_e^*} = 6$$

Formula (s):

$$E_F = \frac{E_g}{2} + \frac{3kT}{4}\log_e\left(\frac{m_h^*}{m_e^*}\right)$$

***Calculation(s)*:**

$$E_F = \frac{1.12\times10^{-19}}{2} + \frac{3\times1.38\times10^{-23}\times300}{4}\log_e(6)$$

$$E_F = 2.41616\times10^{-21} + 5.6\times10^{-20}\,J$$

$$E_F = \frac{2.41616\times10^{-21} + 5.6\times10^{-20}}{1.6\times10^{-19}}\,eV$$

E_F = 0.365 eV

Results:

Fermi Energy E_F = 0.365 eV

5. **A copper strip 2 cm wide and 1 mm thick is placed in a magnetic field with B = 1.5 Wb/m^2 perpendicular to the strip. Suppose a current of 200 A is set up in the strip. What Hall potential difference would appear across the strip? (N = 8.4 x 10^{28} electrons / m^3) (*May. 2015*).**

Given data (s):
Current (I_x) = 200 A
Magnetic field (B_Z) = 1.5 Wbm^{-2}
No. of electrons / volume (n) = 8.4 x 10^{28} m^{-3}
Thickness of the sample (t) = 1 x 10^{-3} m

Formula (s):

Hall voltage $V_H = \frac{R_H I_X B_Z}{t}$

(or) $V_H = \frac{I_X B_Z}{net}$ (Since $R_H = 1 / ne$)

***Calculation(s)*:**

$$V_H = \frac{200\times1.5}{(8.4\times10^{28})(1.6\times10^{-19})(1\times10^{-3})} = 2.2\times10^{-5}V$$

Result(s):

Hall voltage V_H = 2.2 x 10^{-5}V

6. **Find the Hall coefficient and electron mobility of germanium for a given sample (length 1 cm, breadth 5mm, thickness 1mm). A current of 5 mA flows from a 1.35 V supply and develops a Hall voltage of 20 mV across the specimen in a magnetic field of 0.45 Wb/m^2 (*May. 2015*).**

Given data (s):
Current (I_x) = 5mA = 5 x 10^{-3} A

Magnetic field (B_Z) = 0.45 Wbm^{-2}
Hall voltage (V_H) = 20 mV = 20 x 10^{-3} V
Length of the sample (l) = 1 cm = 1 x 10^{-2} m
Breadth of the sample (b) = 5 mm = 5 x 10^{-3} m
Thickness of the sample (t) = 1 mm = 1 x 10^{-3} m

Formula (s):

(i) Resistivity $\rho = \frac{RA}{l}$

(ii) Resistance (R) = V / I

(iii) Hall field (E_H) = V_H / t

(iv) Current density (J) = I / A (or) J = current / (breadth x thickness)

(v) Hall coefficient $R_H = \frac{E_H}{J_X B_Z}$

(vi) Electron mobility $\mu_e = \frac{R_H}{\rho}$

***Calculation(s)*:**

(i) $R = \frac{1.35}{(5\times10^{-3})} = 270\Omega$

(ii) $A = 5\times10^{-3}\times1\times10^{-3} = 5\times10^{-6}m^2$

(iii) $\rho = \frac{270\times5\times10^{-6}}{1\times10^{-2}} = 0.135\Omega m$

(iv) $E_H = \frac{20\times10^{-3}}{1\times10^{-3}} = 20Vm^{-1}$

(v) $J_X = \frac{5\times10^{-3}}{5\times10^{-6}} = 10^3 Am^{-2}$

(vi) $R_H = \frac{20}{10^3\times0.45} = 0.044m^3C^{-1}$

(vii) $\mu_e = \frac{0.044}{0.135} = 0.33m^2V^{-1}S^{-1}$

Result(s):

(i) Resistivity (ρ) = 0.135 Ω m

(ii) Hall field (E_H) = 20 Vm^{-1}

(iii) Current density (J_X) = 10^3 A/m^2

(iv) Hall coefficient (R_H) = 0.044 m^3 C^{-1}

(v) Mobility (μ_e) = 0.33 m^2 V^{-1} S^{-1}.

7. **A semiconductor has a mobility of 500 cm^2 V^{-1} S^{-1} at T = 300 K. Calculate the diffusion coefficient.**

Given data (s):
Mobility (μ_e) = 500 cm^2 V^{-1} S^{-1}
Temperature (T) = 300 K
Boltzmann constant (k) = 1.38 x 10^{-23} J K^{-1}
Charge of electron (e) = 1.6 x 10^{-19} C
Formula(s):

$$D = \left(\frac{kT}{e}\right)\mu$$

Calculations(s):

$$D = \left(\frac{1.38\times10^{-23}\times300}{1.6\times10^{-19}}\right)\times500 = 12.94\ \mathbf{cm^2\ /sec}$$

Result:

Diffusion coefficient = 12.94 cm^2/sec.

8. **A metal-semiconductor contact is formed between gold and *n* type silicon doped to a level N_d = 5 x 10^{16} cm^{-3} at 300 K. Calculate the ideal Schottky barrier height, difference between Fermi level and conduction band of semiconductor and built in potential of the Schottky diode? Assume the work function of gold is 5.1 eV. The electron affinity in semiconductor is 4.01 eV. The effective density of states function N_c = 2.8 x 10^{19} cm^{-3}**

Given data(s):
N_c = 2.8 x 10^{19} cm^{-3}
N_d = 5 x 10^{16} cm^{-3}
T = 300 K
ϕ_m = 5.1eV
χ_{semi} = 4.01 eV
Boltzmann constant (k) = 1.38 x 10^{-23} J K^{-1}
Charge of electron (e) = 1.6 x 10^{-19} C

Formula (s):

(i) Ideal Schottky barrier height $\phi_{Bh} = \phi_m - \chi_{semi}$

(ii) Difference between E_F and conduction band of semiconductor $\phi_n = \frac{kT}{e} \ln\left(\frac{N_c}{N_d}\right)$

(iii) Build in potential barrier $V_{buildin} = \frac{\phi_{Bh} - \phi_n}{e}$

Calculation(s)

(i) $\phi_{Bh} = 5.1 - 4.01 = 1.09 eV$

(ii) $\phi_n = \frac{1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}} \ln\left(\frac{2.8 \times 10^{19}}{5 \times 10^{16}}\right) = 0.164V$

(iii) $V_{buildin} = \frac{1.09 - 0.164}{1} = 0.926V$

Result(s):

Ideal Schottky barrier height = 1.09 eV

Difference between E_F and conduction band of semiconductor = 0.164 V

Build in potential V_{build} = 0.926 V