Review Question Problems Solution

Problem no. 14: Find the resistivity of intrinsic germanium at 300K. Given that the intrinsic density of carriers is 2.5×10^{19} /m^3, electron mobility is 0.38 m^2/V-s, hole mobility is 0.18 m^2/Vs.

Solution: Given- $n_i = 2.5 \times 10^{19}/\,m^3$, $\mu_e = 0.38\ m^2/Vs$, $\mu_h = 0.18\ m^2/Vs$

$$\sigma_i = en_i(\mu_e + \mu_h)$$

$$\rho_i = \frac{1}{en_i(\mu_e + \mu_h)} = \frac{1}{1.6 \times 10^{-19} \times 2.5 \times 10^{19} \times (0.38 + 0.18)}$$

$$\rho_i = 0.446\ \Omega m.$$

Problem No. 15: In a p-type germanium, $n_i = 2.1 \times 10^{19}/m^3$, density of boron = 4.5×10^{23} atoms m^{-3}. The electron and hole mobility are 0.4 and 0.2 m^2/Vs respectively. What is its conductivity before and after the addition of boron atoms?

Solution: $n_i = 2.1 \times 10^{19}/m^3$, $n_{boron} = 4.5 \times 10^{23}$ atoms/m^3, $\mu_e = 0.4\ m^2/Vs$, $\mu_h = 0.2\ m^2/Vs$

Before adding boron atoms, the semiconductor is intrinsic in nature

$$\sigma_i = en_i(\mu_e + \mu_h)$$

$$= 2.1 \times 10^{19} \times 1.6 \times 10^{-19} \times (0.4 + 0.2)$$

$$\sigma_i = 2.016\ \Omega^{-1}m^{-1}$$

After adding boron atoms, the semiconductor becomes a p type

$$\sigma_{boron} = n_{boron}\, e\, \mu_h$$

$$= 4.5 \times 10^{23} \times 1.6 \times 10^{-19} \times (0.2)$$

$$= 1.44 \times 10^{4}\ \Omega^{-1}m^{-1}$$

Problem No. 16: Consider a sample of n-type silicon with $N_d = 10^{21}$ /m^3. Determine the electron and hole densities at 300K. The intrinsic carrier concentration for Si is 9.8×10^{15} /m^3.

Solution: $n_i = 9.8 \times 10^{15}/m^3$, $N_d = 10^{21}$ /m^3

$$n.p = n_i^2$$

Therefore, $n = N_d = 10^{21}$ /m^3

$$N_d.p = n_i^2$$

$$p = \frac{n_i^2}{N_d} = \frac{(9.8 \times 10^{15})^2}{10^{21}} = 9.604 \times 10^{10}/\,m^3$$

Electron density at 300K = n = 10^{21}/m^3

Hole density at 300K= p = 9.604×10^{10}/m^3.

Problem No. 17: A sample of silicon is doped with $4x10^{16}/cm^3$ of Gallium (a group III atom). What are the concentrations of electrons and holes? (Given $n_i = 1.45 \times 10^{10}\ /cm^3$)

Solution: As a group III atom, gallium functions as a acceptor, so the doped material is p-type. The density of holes is essentially equal to the density of acceptors, so

$p = N_A = 4 \times 10^{16}\ /m^3$

The density of electrons is given by the mass action law as,

$$n = \frac{n_i^2}{p} = \frac{n_i^2}{N_A} = \frac{(1.45 \times 10^{10})^2}{4 \times 10^{16}}$$

$n = 5.3 \times 10^3/cm^3$

Problem No. 18: The electron and hole mobilities of Si sample are 0.135 and 0.048 m^2/Vs respectively. Density of silicon atoms $n_i = 1.5 \times 10^{16}\ m^{-3}$. Determine the conductivity of Intrinsic Si at 300 K. The sample is then doped with 10^{23} phosphorous atom/m^3. Determine the equilibrium hole concentration and conductivity.

Solution: $\mu_e = 0.135\ m^2/Vs$, $\mu_h = 0.048\ m^2/Vs$

$n_i = 1.5 \times 10^{16}\ m^{-3}$ $\sigma_{Si} = ?$ at 300K

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

$$= 1.5 \times 10^{16} \times 1.6 \times 10^{-19} \times (0.135 + 0.048)$$

$$\sigma_i = 0.44 \times 10^{-3}\ \Omega^{-1}m^{-1}$$

The sample doped with 10^{23} phosphurus atoms /m^3

$n = N_d = 10^{23}\ /m^3$

$$\sigma_{doped} = N_d \mu_e e$$

$$= 10^{23} \times 1.6 \times 10^{-19}\ (0.135)$$

$$\sigma_{doped} = 2.16 \times 10^3\ \Omega^{-1}m^{-1}$$

Equilibrium hole concentration, $p = \frac{n_i^2}{N_d} = \frac{(1.5 \times 10^{16})^2}{10^{23}}$

$p = 2.25 \times 10^9\ /m^3$

Problem No. 19: Calculate the drift velocity for electrons and holes in a 1mm length of silicon at 27 °C when the terminal voltage is 10V. (Given $\mu_e = 1500\ cm^2/Vs$ and $\mu_h = 500\ cm^2/Vs$)

Solution: l = 1mm, V=10 V,

$\mu_e = 1500\ cm^2/Vs = 0.15\ m^2/Vs$

$\mu_h = 500\ cm^2/Vs = 0.05\ m^2/Vs$

Drift current velocity for electrons, $v_e = \frac{-\mu_n V}{l}$

$$= \frac{-0.1500 \times 10}{1 X 10^{-23}}$$

$$v_e = -1500\ m/s$$

Drift current velocity for electrons, $v_h = \frac{-\mu_p V}{l}$

$$= \frac{-0.1500 \times 10}{1 \times 10^{-23}}$$

$$v_h = 500\ m/s$$

Problem No. 20: An n-type semiconductor sample has a donar density of $10^{21}/m^3$. It is arranged in a Hall experiment having magnetic field of 0.5 T and the current density is 500 A/m^2. Find the Hall voltage if the sample is 3mm wide.

Solution: $N_d = 10^{21}\ /m^3$, B = 0.5 T, J = 500 A/m^2, w = 3mm, V_H =?

Hall Voltage,

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

$$= \frac{J.w.t.B}{t.n.e}$$

$$= \frac{500 \times 0.5 \times 3 \times 10^{-3}}{1.6 \times 10^{-19} \times 10^{21}}$$

$$V_H = 4.6875 \times 10^{-3}\ V$$

J = I/A

I = J.A

I = J.w.t and

$R_H = -\frac{1}{ne}$ and $n = N_D$

Problem No. 21: Hall coefficient of a specimen of doped silicon found to be $3.66 \times 10^{-4} m^3C^{-1}$. The resistivity of the specimen is 8.93×10^{-3} m. Find the mobility and density of the charge carriers

Solution: $R_H = 3.66 \times 10^{-4} m^3C^{-1}$, $\rho = 8.93 \times 10^{-3}$ m

Find μ and p

Since R_H is positive, the semiconductor is p type

$$R_H = \frac{1}{pe}$$

therefore,

$$p = \frac{1}{R_H e} = \frac{1}{1.6 \times 10^{-19} \times 3.66 \times 10^{-4}}$$

$$= 1.7 \times 10^{22} / m^3$$

$\sigma = 1/\rho$

$\mu_h = \sigma/pe$

$$= \frac{1}{\rho.p.e} = \frac{1}{1.6 \times 10^{-19} \times 8.93 \times 10^{-3} \times 1.7 \times 10^{22}}$$

$= 0.0412\ m^2/\ Vs$