Tutorial - 2

Ch - 2 Transport phenomena in semiconductors.

* Numericals.

1. (a) Determine the concentration of free electrons and holes in a sample of Ge at 300 °K which has a concentration of donor atoms equal to 2×10^{14} Atoms/cm³. Is this P-Type or n-type Ge?

   (b) Repeat part (a) if Donor and acceptor concentration are equal and they are 10^{15} Atoms/cm3.

   (c) Repeat part (a) if Donor concentration of 10^{16} atoms/cm³ and acceptor concentration of 10^{14} Atoms/cm3.

Ans- For any semiconductor, from mass Action low.

$$n \cdot P = n_i^2 \quad \text{—— (1)}$$

and from it's electrical property.

$$N_A + n = N_D + P.$$

$$\therefore P = N_A + n - N_D \quad \text{—— (2).}$$

→ By putting eq 2 in eq 1, we get.

$$n \cdot (N_A + n - N_D) = n_i^2$$

$$\therefore n^2 + (N_A - N_D)\, n - n_i^2 = 0 \quad \text{—— (3).}$$

→ Eq 3 is quadratic equation, the solution of this

$$n = \frac{-(N_A - N_D) \pm \boxed{\sqrt{(N_A - N_D)^2 + 4n_i^2}}}{2}$$

→ It is A

→ Since -ve of A may give us n -ve, but it is not possible so neglecting the negative root, so finally

$$n = -\frac{(N_A - N_D)}{2} + \sqrt{\frac{(N_A - N_D)^2}{4} + n_i^2} \quad \text{—— (4)}$$

[Note - To prove whethere material is p type or n-type, we have to find the value of p and n.
-> And if p > n -> then material is p type or vice-versa.
-> To find p and n we can use eq 2 and eq 4 respectively]

-> Now

Ans-a) Given

$N_D = 2 \times 10^{14}$ Atoms/cm^3

$N_A = 3 \times 10^{14}$ Atoms/cm^3

$n_i = 2.5 \times 10^{13}$ Atoms/cm^3.

-> From eq 4

$$n = -\frac{(3-2)}{2} \times 10^{14} + \sqrt{\frac{(3-2)^2 \times 10^{28}}{4} + 6.25 \times 10^{26}}$$

$$\boxed{n = 5.9 \times 10^{12} \text{ electrons/cm}^3}$$

-> From eq 2

$$p = \underbrace{(3 \times 10^{14})}_{N_A} + \underbrace{(5.9 \times 10^{12})}_{n} - \underbrace{(2 \times 10^{14})}_{N_D}$$

$$\boxed{p = 1.059 \times 10^{14} \text{ holes/cm}^3}$$

-> Here, p > n

So Ge is P-Type.

Ans-b) Here $N_A = N_D = 10^{15}$ atoms/cm^3

So $n = p = n_i = 2.5 \times 10^{13}$ Atoms/cm^3

∴ Ge is intrinsic

Ans-c) $N_D = 10^{16}$ Atoms/cm^3

$N_A = 10^{14}$ Atoms/cm^3

-> from eq 4

$$n = -\frac{(10^{14} - 10^{16})}{2} + \sqrt{\frac{(10^{14} - 10^{16})^2}{4} + 6.25 \times 10^{26}}$$

$$\boxed{n = 9.9 \times 10^{15} \text{ electrons/cm}^3}$$

-> so here, n > p
Hence Ge is n-Type.

-> from eq 2

$$\boxed{p = 6.313 \times 10^{10} \text{ Holes/cm}^3}$$

2)
(a) Find the concentration of holes and electrons in p-type Ge at 300°K if conductivity is 100 $(\Omega^{-1}\text{-cm}^{-1})$

(b) Repeat part (a) for N-Type Si if conductivity is 0.1 $(\Omega.\text{cm})^{-1}$.

Ans- Given

$\sigma = 100\ (\Omega.\text{cm})^{-1}$ for Ge
$\mu_p = 1800\ \text{cm}^2/\text{V.s}$ for Ge
$n_i^2 = 2.5 \times 10^{13}$ ~~Atoms~~ Elec/Hole /cm^3 for Ge

General equation for σ in semiconductors
$\rightarrow \sigma = (P\mu_p + n\mu_n)q$

Ans-a) For P-Type semiconductor, Ge.

$\sigma \cong P\mu_p q$ $\quad$ ($\because$ in p type $P \gg n$).

$\therefore P_p = \dfrac{\sigma}{\mu_p q}$

$\therefore P_p = \dfrac{100}{1.6 \times 10^{-19} \times 1800}$

$\boxed{\therefore P_p = 3.47 \times 10^{17}\ \text{Holes/cm}^3}$

Also

$\rightarrow n_p \cdot P_p = n_i^2$

$\therefore n_p = \dfrac{n_i^2}{P_p}$

$= \dfrac{(2.5 \times 10^{13})^2}{3.47 \times 10^{14}}$

$\boxed{\therefore n_p = 1.8 \times 10^{9}\ \text{Ele/cm}^3}$

-> Here Subscript p and n to Hole and Elect. concentration denotes for p and N-Type respectively.

Ans-b) For Si

$n_i^2 = 1.5 \times 10^{10}$ Atoms/cm^3
$\mu_n = 1300\ \text{cm}^2/\text{V.s}$.
$\sigma =$

-> for N-type semiconductor.

$\sigma = n_n \mu_n q$

$\therefore n_n = \dfrac{\sigma}{\mu_n q}$

$= \dfrac{0.1}{1.6 \times 10^{-19} \times 1300}$

$\boxed{\therefore n_n = 4.807 \times 10^{14}\ \text{electrons/cm}^3}$

-> Also

$P_n = \dfrac{n_i^2}{n_n}$

$= \dfrac{(1.5 \times 10^{10})^2}{4.807 \times 10^{14}}$

$\boxed{P_n = 4.68 \times 10^{5}\ \text{Holes/cm}^3}$

3)

(a) Find the resistivity of intrinsic Ge at 300 K.

(b) If a donor type impurity is added to the extent of 1 atom per 10^8 Ge, atoms find the resistivity.

(c) Repeat part (a) and (b) for instrinsic Si at 300 K.

Ans -

(a) For intrinsic semiconductor

$$n = p = n_i$$

→ Also,

$$\sigma = \sigma_n + \sigma_p$$

$$= (n\mu_n + p\mu_p)q \quad \text{—— (1)}$$

→ But Here $n = p = n_i^2$

$$\sigma = (\mu_n + \mu_p) n_i q.$$

$$\therefore \sigma = (3800 + 1800) \times 2.5 \times 10^{13} \times 1.6 \times 10^{-19}$$

$$= 2.24 \times 10^{-2} \ (\Omega.cm)^{-1}$$

→ Now

Resistivity $= 1/\sigma$

$$\boxed{\text{Resistivity} = 44.64 \ (\Omega.cm).}$$

Ans - b) → Here Donor impurities are Added only so eq (1) becomes

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

$$= N_D.q.\mu_n \quad \text{—— (2)} \quad (\because n = N_D \text{ for N-Type})$$

→ Here, First $N_D = ?$

Atoms in Ge $= 4.4 \times 10^{14}$ Atoms / cm^3 ($\because$ from Table 2-1 in book)

→ Here, Ge is doped by the extent of 1 atom per 10^{18} Ge.

→ It means

For 10^8 Atoms of Ge → 1 Atom of Donor

$\therefore$ 4.4×10^{22} " " " → (?)

$$\therefore N_D = \frac{4.4 \times 10^{22}}{10^8}$$

$$= 4.4 \times 10^{14} \text{ atoms/cm}^3.$$

→ Putting the values of N_D and μ_n in eq 2

$$\therefore \sigma = 4.4 \times 10^{14} \times 3800 \times 1.6 \times 10^{-19}$$

$$= 0.268 \ (\Omega \cdot cm)^{-1}$$

→ $\boxed{\text{Resistivity} = 1/\sigma = 3.72 \ (\Omega . cm)}$

Ans - c) $\sigma = (\mu_n + \mu_p) n_i q$ for intrinsic Si.

→ Now From Table 2-1 of book for Si.

$\mu_n = 1300 \text{ cm}^2/V.s$

$\mu_p = 500 \text{ cm}^2/V.s.$

$n_i = 1.5 \times 10^{10}$ ~~Atom~~ Elect or Hole/cm^3.

No. of Atoms/cm^3 = 5×10^{22}.

→ Now,

$$\sigma = (\mu_n + \mu_p) n_i q.$$

$$= (1300 + 500) \times 1.5 \times 10^{10} \times 1.6 \times 10^{-19}.$$

$$= 4.32 \times 10^{-6} \ (\Omega . cm)$$

→ Also

$\boxed{\text{Resistivity} = 1/\sigma = 2,31,481 \ (\Omega . cm)}$