## Mass-action law

$$n \cdot p = n_i^2$$

no. of elect/$m^3$ — no. of holes/$m^3$ — intr. conc.

**Intrinsic S.C**

conductivity $\Rightarrow$ $\boxed{\sigma_i = q n_i (\mu_n + \mu_p)}$

**Extrinsic conductivity**

n type $\Rightarrow$ $\sigma_N = q n_N \mu_n = q N_D \mu_n$

p type $\Rightarrow$ $\sigma_p = q p_p \mu_p = q N_A \mu_p$

## Charge densities in n & p

$N_D \rightarrow$ conc of donor atoms

$$n_N = N_D + p_N \simeq N_D$$

when $p_N = \dfrac{n_i^2}{n_N} = \dfrac{n_i^2}{N_D} \ll n_N$ or $N_D$

||ly in ptype

conc. of accep. atoms

$$p_p = N_A + n_p \simeq N_A$$

when, $n_p = \dfrac{n_i^2}{p_p} = \dfrac{n_i^2}{N_A} \ll p_p$ or $N_A$

## Problem

1) In PN jn. diode at $T = 300K$, Si, $n_i = 1.5 \times 10^{10}\ cm^{-3}$, $V_F = 0.6V$

$N_D = n = 1 \times 10^{10}\ cm^{-3}$

Find the conc. of holes (p).

$n \cdot p = n_i^2$

Conc. of holes:

$$\Rightarrow p = \frac{n_i^2}{n} = \frac{(1.5 \times 10^{10})^2}{1 \times 10^{10}} = 2.25 \times 10^{10}\ cm^{-3}$$

(2) Determine the conductivity $\sigma$ of Si

i) intrinsic condition at 300K

ii) with donor impurity of 1 in $10^8$

iii) with acceptor impurity of 1 in $5 \times 10^7$

iv) with both the above impurities

Given that $n_i = 1.5 \times 10^{10}\ cm^{-3}$, $\left.\begin{array}{l} \mu_n = 1300\ cm^2/V\text{-}s \\ \mu_p = 500\ cm^2/V\text{-}s \end{array}\right\}$ for Si

no. of Si atoms/$cm^3$ $= 5 \times 10^{22}$

(i) Intrinsic condition, $n = p = n_i$

Conductivity

$$\Rightarrow \sigma_i = q\, n_i (\mu_n + \mu_p)$$

$$= (1.602 \times 10^{-19}) \times (1.5 \times 10^{10}) \times (1300 + 500)$$

$$\sigma_i = 4.32 \times 10^{-6} \ S/cm$$

(ii) No. of Si atoms $/cm^3 = 5 \times 10^{22}$ (Given)

For $10^8$ Si atoms $= 1$ (donor impurity added)

For $5 \times 10^{22}$ Si atoms $= \frac{1}{10^8} \times 5 \times 10^{22} = 5 \times 10^{14} \ cm^{-3} = N_D$

For N type $\Rightarrow n \simeq N_D$, so $p = \frac{n_i^2}{n} \simeq \frac{n_i^2}{N_D} = \frac{(1.5 \times 10^{10})^2}{5 \times 10^{14}} = 0.46 \times 10^{6} \ cm^{-3}$

$p \ll n$, Hence $p$ can be neglected i.e, $0.46 \times 10^{6} \ll 5 \times 10^{14}$

$p \ll n$ (for N type)

For N type, Conductivity, $\sigma_N = nq\mu_n = N_D q \mu_n$

$$= (5\times10^{14}) \times (1.602\times10^{-19}) \times 1300$$

$$\sigma_N = 0.104 \ S/cm$$

(iii) No. of Si atoms / $cm^3$ = $5\times10^{22}$ (Given)

For $5\times10^{7}$ Si atom = 1 (acceptor impurity added)

$\therefore$ For $5\times10^{22}$ Si atoms $= \dfrac{1}{5\times10^{7}} \times 5\times10^{22} = 10^{15}\ cm^{-3} = N_A$

For p type $\Rightarrow p \approx N_A$, So $n = \dfrac{n_i^2}{p} \simeq \dfrac{n_i^2}{N_A} = \dfrac{(1.5\times10^{10})^2}{10^{15}} = 2.25\times10^{5}\ cm^{-3}$

$n \ll p$, Hence $n$ can be neglected

i.e, $2.25\times10^{5} \ll 10^{15}$

$n \ll p$ (for p type)

For P type, Conductivity, $\sigma_p = p q \mu_p = N_A q \mu_p$

$$= 10^{15} \times 1.602 \times 10^{-19} \times 500$$

$$\sigma_p = 0.08 \ S/cm$$

(iv) With both types of impurities are added, then the net acceptor impurity density is $N_A' = N_A - N_D = 10^{15} - 5 \times 10^{14} = 5 \times 10^{14} \ cm^{-3}$

Conductivity, $\sigma = N_A' q \mu_p = (5 \times 10^{14}) \times (1.602 \times 10^{-19}) \times 500$

$$\sigma = 0.04 \ S/cm$$

Suppose if resistivity is asked, then $\rho = \frac{1}{\sigma}$ in $\Omega \cdot cm$
($\rho$) for the above problem