Intrinsic Semi-Cond.

$n = p = n_i$ $\quad$ T, Ionization Energy

$\sim 1 eV$

Si — 1.1 eV

Ge - 0.7 eV

Extrinsic Semi Cond.

$\sim 0.1 eV$

Group $\underline{V}$ elements (P, As, Sb)

Group $\underline{III}$ elements (B, Al ...)

5th electron of Group V dopant is "relatively free" — Ionization energy ~ 0.1 eV

$n \neq p$

"Kinetic Theory of Gas"

'T' $\langle \text{Energy} \rangle \simeq \frac{3}{2} kT$

k = Boltzmann Const $= 1.38 \times 10^{-23}$ J/K $\simeq 8.62 \times 10^{-5}$ eV/K

$T = 300K$ $kT = 0.0259$ eV

$0.1\,eV \sim 4\,kT$

$1\,eV \sim 40\,kT$ → $10^{10}/cm^3$ at $T = 300k$ for Si

Phosphorus (P)

$10^{17}/cm^3$ → Impurity

Silicon

10^{22} atoms/cm^3

Extrinsic or Impure Silicon

1 P atom → 1 relatively free electron

10^{17} P atom/cm^3 → 10^{17} relatively free electrons/cm^3

↓

Conduction electron

Generation process (Thermal Generation)

(donor) Group V dopants → electrons

(acceptor) Group III dopant → holes

Recombination process

10^{10} broken bonds / cm^3 for intrinsic Si at $T = 300K$

Recombination Rate $R \propto np$

$$R = \alpha_r np$$

Generation rate $G_{th} = f(T)$

$\neq f$ (doping conc.)

At equilibrium $R = G_{th}$

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

$$np = n_i^2$$

Mass Action law

Extrinsic Semiconductor

- Group V → More Electrons (N-type) (Majority electron, Minority hole)
- Group III → More Holes (P-type) (Majority hole, Minority electron)

Charge neutrality

Sources of +ve charge → p, N_D^+

Sources of −ve charge → n, N_A^-

$$+q\,(p + N_D^+) + (-q)\,(n + N_A^-) = 0$$

$$p + N_D^+ = n + N_A^-$$ Charge neutrality condition

Si at T = 300K, $n_i = 10^{10}/cm^3$

Case-1: Phosphorus (P) $\longrightarrow$ $N_D = 10^{16}/cm^3$

Case-2: Boron (B) $\longrightarrow$ $N_A = 10^{17}/cm^3$

$n_1 p_1 = n_i^2$

$n_1 = \cancel{p_1} + N_D$

$$n_1 = \frac{n_i^2}{n_1} + N_D$$

$$n_1^2 - n_1 N_D - n_i^2 = 0$$

$$\Rightarrow n_1 = \frac{N_D \pm \sqrt{N_D^2 + 4n_i^2}}{2} \approx N_D = 10^{26}/cm^3$$

$$p_1 = n_i^2 / N_D = 10^4/cm^3$$

Case 2

$$n_2 p_2 = n_i^2$$

$$n_2 + N_A = p_2 + N_D$$

$$\frac{n_i^2}{p_2} + N_A = p_2 + N_D$$

$$\Rightarrow p_2^2 - (N_A - N_D)\,p_2 - n_i^2 = 0$$

$$p_2 = \frac{N_A - N_D \pm \sqrt{(N_A - N_D)^2 + 4n_i^2}}{2}$$

$$= \frac{9\times10^{16} \pm \sqrt{81\times10^{32} + 4\times10^{20}}}{2}$$

$$= 9\times10^{16}/cm^3$$

$$n_2 \approx 10^3/cm^3$$

n or p can be high

$$np = n_i^2$$

$$n + N_A^- = p + N_D^+$$