HW 1 Solution Problem 1-3

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1\.

Section 3.2: Doped Semiconductors

3.3 For a p-type silicon in which the dopant concentration $N_A = 5 \times 10^{18}/\text{cm}^3$, find the hole and electron concentrations at $T = 300$ K.

From Example 3-1 $n_i = 1.5 \times 10^{10}/\text{cm}^3$ at 300 K

(more precise than $10^{10}/\text{cm}^3$ used in the lecture)

$$p \cong N_A = \boxed{5 \times 10^{18}/\text{cm}^3}$$

(100% ionization)

$$np = n_i^2, \quad n = \frac{n_i^2}{p} = \frac{(1.5 \times 10^{10})^2}{5 \times 10^{18}} = \boxed{45/\text{cm}^3} \ll p$$

2\. **3.4** For a silicon crystal doped with phosphorus, what must N_D be if at $T = 300$ K the hole concentration drops below the intrinsic level by a factor of 10^8?

P (phosphorus) beongs to Group V family of periodic Table ⇒ donor ⇒ n-type

$$p = \frac{n_i^2}{n} \simeq \frac{n_i^2}{N_d}$$

Set $p < \frac{n_i}{10^8}$

$$\frac{n_i^2}{N_d} < \frac{n_i}{10^8}$$

$$N_d > n_i \cdot 10^8$$

$$N_d > 1.5 \times 10^{10} \cdot 10^8$$

$$N_d > \boxed{1.5 \times 10^{18}/\text{cm}^3}$$

3 **3.5** In a phosphorus-doped silicon layer with impurity concentration of $10^{17}/\text{cm}^3$, find the hole and electron concentrations at 27°C and 125°C.

$$n_i = 7.3 \times 10^{15} (300)^{3/2} e^{-1.12/(2 \times 8.62 \times 10^{-5} \times 300)}$$
$$= 1.5 \times 10^{10} \text{carriers/cm}^3$$

$n \simeq N_d = 10^{17}/\text{cm}^3$ at all temp. above freeze out temp (~10-20K)

$$p = \frac{n_i^2}{n}$$

$$n_i(T) = B \cdot T^{3/2} \cdot e^{-E_g/2kT} \quad \text{— (1)}$$

$$n_i(300) = B\,(300)^{3/2}\, e^{-\frac{E_g}{2k}\left(\frac{1}{300}\right)} \quad \text{— (2)}$$

$\frac{(1)}{(2)}$:

$$n_i(T) = n_i(300) \cdot \left(\frac{T}{300}\right)^{3/2} \cdot e^{-\frac{E_g}{2k}\left(\frac{1}{T} - \frac{1}{300}\right)}, \quad E_g = 1.12\ eV, \quad k = 8.62\times10^{-5}\ eV/K$$

Kelvin

Boltzman's Constant

expressing $n_i(T)$ using $n_i(300) = 1.5\times10^{10}$ as a reference

$$\boxed{n_i(T) = 1.5\times10^{10} \left(\frac{T}{300}\right)^{3/2} e^{-\frac{1.12}{2(8.6\times10^{-5})}\left(\frac{1}{T} - \frac{1}{300}\right)}}$$

at $27^\circ C$ (300K), $\boxed{n = 10^{17}/cm^3}$, $p = \frac{(1.5\times10^{10})^2}{10^{17}} = \boxed{2.25\times10^3/cm^3}$

at $125^\circ C$ $(273+125 = 398\,K)$, $\boxed{n = 10^{17}/cm^3}$, $n_i = 4.8\times10^{12}/cm^3$

$$p = \frac{n_i^2}{n} = \frac{(4.8\times10^{12})^2}{10^{17}} = \boxed{2.3\times10^8/cm^3}$$

Significance of $125^\circ C$: This is the around the Max. operating temp of Si IC.