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6.012 Problem Set #1 Solutions - Fall 2000

Problem #1 : E2.1

At RT, $n_i = 10^{10}\ cm^{-3}$

a) Since $N_d \gg n_i$, $\boxed{n_o = N_d = 10^{15}\ cm^{-3}}$

b) $p_o = \frac{n_i^2}{n_o} = \frac{10^{20}}{10^{15}} = \boxed{10^5\ cm^{-3}}$

Problem #2 : E2.4

a) Since $N_a > N_d$, holes are the majority carrier. This is a compensated p-type Si.

b) Since $N_a - N_d \gg n_i$, $p_o = N_a - N_d = \boxed{5\times10^{16}\ cm^{-3}}$

c) $n_o = \frac{n_i^2}{N_a - N_d} = \boxed{2\times10^3\ cm^{-3}}$

Problem #3 : E2.5

Wafer initially doped with $N_a = 10^{14}\ cm^{-3}$ ($p_o = 10^{14}\ cm^{-3}$). Must be compensated with N_d to yield $p_o = 10^{13}\ cm^{-3}$.

$p_o = N_a - N_d$

$\boxed{N_d = 9\times10^{13}\ cm^{-3}}$

Problem #4 : E2.6 ⇒ Low doping - need to include thermal generation

$8n_i = n_o = \frac{N_d}{2} + \frac{N_d}{2}\sqrt{1+\frac{4n_i^2}{N_d^2}} \Rightarrow \frac{n_i^2}{n_o} + N_d - n_o = 0$

$\boxed{N_d = 7.875\, n_i}$ At RT, $N_d = 7.875\times10^{10}\ cm^{-3}$

Not taking thermal generation into account results in $\frac{0.125}{7.875} = 1.6\%$ error.

Problem #5 : E2.7

$n_o = 5\times10^{14}\ cm^{-3}$ $\quad 1\ \mu m = 10^{-4}\ cm$

$p_o = \frac{n_i^2}{n_o} = 2\times10^5\ cm^{-3}$ $\quad 1\ \mu m^3 = 10^{-12}\ cm^3$

e^- in $1\ \mu m^3$ volume = 500 electrons

h^+ in $1\ \mu m^3$ volume = 2×10^{-7} holes

As the dimensions are scaled down, the number of carriers decrease as the cube of the linear dimension. This can be compensated by increasing the doping.

Problem #6 : P2.2

3 impurities : As: $10^{16}\ cm^{-3}$ (Group V → N_d)

B: $1.15\times10^{16}\ cm^{-3}$ (Group III → N_a)

P: $2.5\times10^{15}\ cm^{-3}$ (Group V → N_d)

$n_o = N_{dAs} + N_{dP} - N_{aB} = \boxed{10^{15}\ cm^{-3}}$ $\quad p_o = \frac{n_i^2}{n_o} = \boxed{10^5\ cm^{-3}}$

Problem #7 : P2.4

Temp (C)	Temp (K)	ni (cm-3)	T^3/2	T^3/2*exp(-6608.7/T)	A=ni/(T^3/2*exp(-6608.7/T))
-55	218.15	2.24E+06	3222.054	2.24841E-10	9.97E+15
0	273.15	1.42E+09	4514.416	1.40316E-07	1.01E+16
70	343.15	2.82E+11	6356.616	2.74904E-05	1.03E+16
125	398.15	5.06E+12	7944.564	0.000491389	1.03E+16
				Ave =	1.02E+16

⇒ $\boxed{A = 1.02\times10^{16}\ K^{-1/2}\ cm^{-3}}$

At 300 K ⇒ $n_i = 1.44\times10^{10}\ cm^{-3}$

Temp at which $n_i = 2.88\times10^{10}\ cm^{-3}$:

$2.88\times10^{10} = A T^{3/2} e^{-6608.7/T} \rightarrow T(\ln(2.88\times10^{10}) - \ln A) = 3/2\, T\ln(T) - 6608$

$T = 517.21 - 0.1174\, T \ln(T)$ → To solve, make a guess & iterate.

T = 305 → 312.38 → 306.55 → 311.16 → 307.51 → 310.4 → 308.1 → 309.9 → 308.5 → 309.6 → 308.7 → 309.4 → 308.9 → 309.3 → 309 → 309.25 → 309.0 → 309.20 → 309.06 → 309.17 → 309.09 → 309.15 → 309.1

Finally converges to 309.1 K.

Problem #7: P2.4 (cont.)

Repeat same procedure to get T when $n_i = 7.2 \times 10^9\ cm^{-3}$

$$T\left(\ln(7.2\times10^9) - \ln(N)\right) = \tfrac{3}{2} T \ln(T) - 6608.7$$

$$T = 466.59 - 0.1059\, T \ln(T) \Rightarrow \text{Converges to } T = 291.4\ K$$

so,

T	n_i
291.4 K	$7.2 \times 10^9\ cm^{-3}$
300 K	$1.44 \times 10^{10}\ cm^{-3}$
309.1 K	$2.88 \times 10^{10}\ cm^{-3}$

Problem #8:

For Ge: (From Graph)

T(C)	$n_i\ (cm^{-3})$
27	2.1×10^{13}
150	2.5×10^{15}
500	1.5×10^{18}

@ 27°C $(N_a - N_d) \gg n_i$ so, $p_o = N_a - N_d = \boxed{5\times10^{15}\ cm^{-3}}$

$$n_o = \frac{n_i^2}{p_o} = \boxed{8.82 \times 10^{10}\ cm^{-3}}$$

@ 150°C $(N_a - N_d) \approx n_i \Rightarrow$ Must take thermal generation into account.

$$p_o = \frac{N_a - N_d}{2} + \frac{N_a - N_d}{2}\sqrt{1 + \frac{4n_i^2}{(N_a - N_d)^2}} = \boxed{6.04 \times 10^{15}\ cm^{-3}}$$

$$n_o = \frac{n_i^2}{p_o} = \boxed{1.03 \times 10^{15}\ cm^{-3}}$$

@ 500°C $(N_a - N_d) \ll n_i$

$$n_o = p_o = n_i = \boxed{1.5 \times 10^{18}\ cm^{-3}}$$