Homework #5

Problems 3.1, 3.3, 3.5, 3.8, and 3.11

Problem 3.1

Find values of the intrinsic carrier concentration n_i for silicon at -55°C, 0°C, 20°C, 75°C, and 125°C. At each temperature, what fraction of the atoms is ionized? Recall that a Silicon crystal has approximately 5 x 10^{22} atoms/cm^3.

$$n_i = BT^{3/2}e^{-E_g/2kT}$$

°C	Kelvin	n_i	ratio
-55	218	2.68E+06	5.37E-17
0	273	1.52E+09	3.05E-14
20	293	8.60E+09	1.72E-13
75	348	3.70E+11	7.40E-12
125	398	4.72E+12	9.45E-11
27	300	1.49E+10	2.99E-13

Problem 3.3

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

$$n_i = BT^{3/2} e^{-E_g/2kT} = 1.5 \times 10^{10}\ 1/\text{cm}^3$$ At 300K

$$p_p \approx N_A = 5 \text{ x } 10^{18}/\text{cm}^3$$

$$n_p \approx n_i^2 / N_A = (1.5 \text{ x } 10^{10})^2/(5 \text{ x } 10^{18}) = 45/\text{cm}^3$$

Problem 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.

$$n_i = BT^{3/2} e^{-E_g/2kT} = 1.5 \times 10^{10}\ 1/\text{cm}^3$$ At 300K (27C)

$$n_n \approx N_D = 10^{17}/\text{cm}^3$$

$$p_n \approx n_i^2/N_D = (1.5\text{x}10^{10})^2/10^{17} = 2.25\text{x}10^3/\text{cm}^3$$

$$n_i = BT^{3/2} e^{-E_g/2kT} = 4.72 \times 10^{12}\ 1/\text{cm}^3$$ At 398K (125C)

$$n_n \approx N_D = 10^{17}/\text{cm}^3$$

$$p_n \approx n_i^2/N_D = (4.72\text{x}10^{12})^2/10^{17} = 2.23\text{x}10^8/\text{cm}^3$$

Problem 3.8

Find the current that flows in a silicon bar of 10-μm length having a 5-μm x 4-μm cross section and having free electron and hole densities of $10^4/cm^3$ and $10^{16}/cm^3$, respectively, when 1 V is applied end-to-end. Use μ_n = 1200 cm²/V·s and μ_p = 500 cm²/V·s.

$$I = I_p + I_n = qA(p\mu_p + n\mu_n)E$$

$$\mu_n := 1200\,\frac{\mathrm{cm}^2}{\mathrm{V\cdot s}} \qquad \mu_p := 500\,\frac{\mathrm{cm}^2}{\mathrm{V\cdot s}} \qquad n_p := \frac{10^4}{\mathrm{cm}^3} \qquad p_p := \frac{10^{16}}{\mathrm{cm}^3}$$

$$q = 1.602 \times 10^{-19}\,C \qquad E_{field} := \frac{1\mathrm{V}}{10\mu\mathrm{m}}$$

$$Area := 5\mu\mathrm{m}\cdot 4\mu\mathrm{m} = 2\times 10^{-7}\cdot\mathrm{cm}^2$$

$$I_{3.8} := q\cdot Area\cdot\left(n_p\cdot\mu_n + p_p\cdot\mu_p\right)\cdot E_{field} = 160.2\cdot\mu\mathrm{A}$$

Problem 3.11

Both the carrier mobility and diffusivity decrease as the doping concentration of silicon is increased. The table below provides a few data points for μ_n and μ_p versus doping concentration. Use the Einstein relationship to obtain the corresponding values for D_n and D_p.

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T$$

Einstein Relationship

At room temperature (~300K) V_T = 25.9 mV

doping concentration (/cm3)	μ_n (cm^2/Vs)	μ_p (cm^2/Vs)	D_n (cm^2/s)	D_p (cm^2/s)
1.50E+10	1350	480	34.965	12.432
1.00E+16	1200	400	31.08	10.36
1.00E+17	750	260	19.425	6.734
1.00E+18	380	160	9.842	4.144