ENGR 305 – Homework 1

3.1 Use the expression in Eq. (3.2), with
$B = 7.3 \times 10^{15}\ \text{cm}^{-3}\text{K}^{-3/2}$;
$k = 8.62 \times 10^{-5}\text{eV/K}$; and $Eg = 1.12\ \text{V}$
we have
$T = -55{\circ}\text{C} = 218\ \text{K}$
$n_i = 2.68 \times 10^6\ \text{cm}^{-3}$; N/n_i
$= 1.9 \times 10^{16}$ and $n_i/N = 5.36 \times 10^{-17}$
That is, one out of every 1.9×10^{16} silicon atoms
is ionized at this temperature.

$T = 0{\circ}\text{C} = 273\ \text{K}$
$n_i = 1.52 \times 10^9\ \text{cm}^{-3}$; N/n_i
$= 3.3 \times 10^{13}$ and $n_i/N = 3.04 \times 10^{-14}$
$T = 20{\circ}\text{C} = 293\ \text{K}$
$n_i = 8.60 \times 10^9\ \text{cm}^{-3}$; N/n_i
$= 5.8 \times 10^{12}$ and $n_i/N = 1.72 \times 10^{-13}$
$T = 75{\circ}\text{C} = 348\ \text{K}$
$n_i = 3.70 \times 10^{11}\ \text{cm}^{-3}$; N/n_i
$= 1.4 \times 10^{11}$ and $n_i/N = 7.4 \times 10^{-12}$
$T = 125{\circ}\text{C} = 398\ \text{K}$
$n_i = 4.72 \times 10^{12}\ \text{cm}^{-3}$; N/n_i
$= 1.1 \times 10^{10}$ and $n_i/N = 9.44 \times 10^{-11}$

3.4 Since $N_A \gg n_i$, we can write
$p_p \approx N_A = 2 \times 10^{18}\ \text{cm}^{-3}$
Using Eq. (3.3), we have
$n_p = n_i^2/p_p$
$= 112.5\ \text{cm}^{-3}$

3.7 (a) The resistivity of silicon is given by
Eq. (3.17).
For intrinsic silicon,

$p = n = n_i = 1.5 \times 10^{10}\ \text{cm}^{-3}$

Using μ_n

$= 1350\ \text{cm}^2/\text{V} \cdot \text{s}$ and

$\mu_p = 480\ \text{cm}^2/\text{V} \cdot \text{s}$, and $q = 1.6 \times 10^{-19}$ C we have

$\rho = 2.28 \times 10^5\ \Omega\text{-cm}$.

Using $R = \rho \cdot L/A$

with $L = 0.0015$ cm and

$A = 3 \times 10^{-8}\ \text{cm}^2$, we have

$R = 11.4 \times 10^9\ \Omega$.

(b) $n_n \approx N_D = 5 \times 10^{16}\ \text{cm}^{-3}$;

$p_n = n_i^2/n_n$

$= 4.5 \times 10^3\ \text{cm}^{-3}$

Using $\mu_n = 1200\ \text{cm}^2/\text{V} \cdot \text{s}$ and

$\mu_p = 400\ \text{cm}^2/\text{V} \cdot \text{s}$, we have

$\rho = 0.10\ \Omega\text{-cm}$; $R = 5\ \text{k}\Omega$.

(c) $n_n \approx N_D = 5 \times 10^{18}\ \text{cm}^{-3}$;

$p_n = n_i^2/n_n$

$= 45\ \text{cm}^{-3}$

Using $\mu_n = 1200\ \text{cm}^2/\text{V} \cdot \text{s}$ and

$\mu_p = 400\ \text{cm}^2/\text{V} \cdot \text{s}$, we have

$\rho = 1.0 \times 10^{-3}\ \Omega\text{-cm}$; $R = 50\ \Omega$.

As expected, since N_D is increased by 100, the resistivity decreases by the same factor.

(d) $p_p \approx N_A = 5 \times 10^{16}\ \text{cm}^{-3}$; $n_p = n_i^2/n_n$

$= 4.5 \times 10^3\ \text{cm}^{-3}$

$\rho = 0.31\ \Omega\text{-cm}$; $R = 15.63\ \text{k}\Omega$

(e) Since ρ is given to be $2.8 \times 10^{-6}\ \Omega\text{-cm}$, we

directly calculate $R = 0.14\ \Omega$.

3.14 From Table 3.1,

V_T at 300 K $= 25.9$ mV

Using Eq. (3.21), built-in voltage V_0 is obtained:

$V_0 = V_T ln\left(\frac{N_A N_D}{n_i^2}\right) = 25.9 \times 10^{-3} \times ln\left(\frac{10^{17}\times 10^{16}}{(1.5\times 10^{10})^2}\right) = 0.754V$

Depletion width

$W = \sqrt{\frac{2\epsilon_S}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)V_0}$ Eq. (3.25)

$$W = \sqrt{\frac{2 \times 1.04 \times 10^{-12}}{1.6 \times 10^{-19}}\left(\frac{1}{10^{17}}+\frac{1}{10^{16}}\right) \times 0.754}$$

$= 0.328 \times 10^{-4}$ cm $= 0.328$ μm

Use Eqs. (3.26) and (3.27) to find x_n and x_p:

$x_n = W\frac{N_A}{N_A+N_D} = 0.328\mu m \times \frac{10^{17}}{10^{17}+10^{16}} = 0.298\mu m$

$x_p = W\frac{N_D}{N_A+N_D} = 0.328\mu m \times \frac{10^{16}}{10^{17}+10^{16}} = 0.03\mu m$

Use Eq. (3.28) to calculate charge stored on either side:

$Q_J = Aq\left(\frac{N_A N_D}{N_A+N_D}\right)W$, where junction area

$A = 10\ \mu m^2 = 10 \times 10^{-8}\ cm^2$

$Q_J = 10 \times 10^{-8} \times 1.6 \times 10^{-19}\left(\frac{10^{17}10^{16}}{10^{17}+10^{16}}\right)\times 0.328 \times 10^{-4}$

Hence, $Q_J = 4.8 \times 10^{-15}C$

3.20 There is a 2-V reverse bias applied across the junction of problem 3.14.

The built-in potential V_0 remains the same; V_0 =0.754 V.

Use equation (3.30) for W,

$$W = \sqrt{\frac{2\epsilon_S}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)(V_0+V_R)} = \sqrt{\frac{2\times 1.04\times 10^{-12}}{1.6\times 10^{-19}}\left(\frac{1}{10^{17}}+\frac{1}{10^{16}}\right)\times(0.754+2)} = 0.627\mu m$$

Use equation (3.31) for Q_J

$Q_J = A\sqrt{2\epsilon_S q\left(\frac{N_A N_D}{N_A+N_D}\right)(V_0+V_R)} =$

$10 \times 10^{-8}\sqrt{2 \times 1.04 \times 10^{-12} \times 1.6 \times 10^{-19}\left(\frac{10^{17}10^{16}}{10^{17}+10^{16}}\right)(2.754)} = 9.13 \times 10^{-15}C$