ECE3040 Assignment 1

1. It is found that Si at $T = 300\,\mathrm{K}$ has the intrinsic concentration $n_i = 1.5 \times 10^{10}$ per cm^3. If the bandgap voltage is $V_G = 1.11\,\mathrm{V}$, show that the constant n_0 in the equation

$$n_i = n_0 \left(\frac{T}{300}\right)^{3/2} \exp\left(\frac{-V_G}{2V_T}\right)$$

has the value $n_0 = 3.04 \times 10^{25}$.

2. Copper has two valence electrons per atom, an atomic weight of $63.546\,\mathrm{g/\,mol}$, a density of $8230\,\mathrm{kg/\,m^3}$, and a conductivity of $5.8 \times 10^7\,\mathrm{S/\,m}$. (a) If all valence electrons are free, show that the concentration of free electrons is $n = 1.56 \times 10^{29}$ electrons per m^3. (b) Show that the electron mobility in copper is $\mu_e = 2.32 \times 10^{-3}\,\mathrm{m^2\,V^{-1}\,s^{-1}}$.

3. Show that the diameter of 1 ft of copper wire required to obtain a resistance of $5\,\Omega$ is $d = 1.44 \times 10^{-3}\,\mathrm{in}$.

4. Let $y = f(x)$. The percentage fractional change in y per change in x is defined by

$$\frac{1}{y} \times \frac{dy}{dx} \times 100\%$$

The intrinsic concentration of silicon is given by

$$n_i = n_0 \left(\frac{T}{300}\right)^{3/2} \exp\left(\frac{-V_G}{2V_T}\right)$$

If $V_G = 1.11\,\mathrm{V}$ and is assumed to be independent of temperature and $V_T = kT/q$, show that the fractional percentage change in the intrinsic concentration for silicon at $T = 300\,\mathrm{K}$ is

$$\left(\frac{3}{2T} + \frac{V_G}{2TV_T}\right) \times 100\% = 7.64\% \text{ per } ^\circ\mathrm{C}$$

5. Let a rod of semiconductor material have a length $\Delta\ell$, a cross-section area S, an intrinsic concentration n_i, an electron mobility μ_e, and a hole mobility μ_h. Show that the resistance of the rod can be written as the parallel combination of two resistors R_e and R_h given by

$$R_e = \frac{\Delta\ell}{n_i \mu_e q S} \qquad R_h = \frac{\Delta\ell}{n_i \mu_h q S}$$

6. A rod of intrinsic silicon is 5 mm long and has a diameter of 1.5 mm. At room temperature, the intrinsic concentration in the silicon is $n_i = 1.5 \times 10^{16}$ per m^3. The electron and hole mobilities are $\mu_e = 0.13\,\mathrm{m^2\,V^{-1}\,s^{-1}}$ and $\mu_h = 0.05\,\mathrm{m^2\,V^{-1}\,s^{-1}}$. Use the results of problem 5 to show that $R_e = 9.06\,\mathrm{M\Omega}$, $R_h = 23.6\,\mathrm{M\Omega}$, and $R = R_e \| R_h = 6.54\,\mathrm{M\Omega}$.

7. In the silicon rod of problem 6, the number of silicon atoms per m^3 is 5×10^{28}. An acceptor impurity is added to the silicon in the rate of one donor atom per 10^8 atoms of silicon. Show that the new resistance of the rod is $R = 706\,\Omega$. Verify that the resistance contributed by the minority electron carriers is negligible. Assume that each acceptor atom contributes one mobile hole.

8. An open-circuited p-n junction is fabricated from silicon. The number of silicon atoms per m^3 is 5×10^{28} and the number of acceptors is one atom per 10^{10} atoms of silicon. The intrinsic concentration is $n_i = 1.5 \times 10^{16}$ per m^3. If the built-in potential is found to be $V_B = 0.5\,\mathrm{V}$, show that the number of donors is one atom per 4.59×10^6 atoms of silicon.

9. (a) If the acceptor and donor concentrations in a semiconductor are equal, i.e. $N_A = N_D$, show that the hole and electron concentrations must be equal, i.e. $p = n$. (b) If $N_A = N_D$ and the mass-action law holds, show that the doped semiconductor behaves as an intrinsic semiconductor. (c) Use the results of the previous parts to show that the effective impurity concentration in a semiconductor is $N_D - N_A$.

10. (a) A silicon semiconductor has $N_D = 10^{20}$ donor atoms per m^3 and $N_A = 7 \times 10^{19}$ acceptor atoms per m^3. The intrinsic concentration is $n_i = 1.5 \times 10^{16}$ atoms per m^3. The electron and hole mobilities are $\mu_n = 0.13\,\mathrm{m}^2/\,\mathrm{V\,s}$ and $\mu_h = 0.05\,\mathrm{m}^2/\,\mathrm{V\,s}$. Use the equations $n + N_A = p + N_D$ and $np = n_i^2$ to show that $n = 3 \times 10^{19}$ electrons per m^3 and $p = 7.5 \times 10^{12}$ holes per m^3. (b) If an applied electric field is $E = 2\,\mathrm{V}/\,\mathrm{cm}$, show that the current density is $J = 12.5\,\mathrm{mA}/\,\mathrm{cm}^2$.