Assignment 3: Extrinsic semiconductors

1. A group IV semiconductor is doped with 10^{18} donor atoms per cm^3. $n_i = 2.3 \times 10^{13}\ cm^{-3}$ and $N_c = N_v = 7 \times 10^{19}\ cm^{-3}$. At 300 K, the donor atoms are fully ionized. What is the hole concentration at 300 K? What is the band gap of the semiconductor? What is the position of the Fermi level with respect to intrinsic semiconductor Fermi level?

2. A semiconductor with $n_i = 10^{16}\ m^{-3}$ (at 300 K) is doped with acceptor impurities to a concentration of $10^{23}\ m^{-3}$.

   (a) What are the electron and hole concentrations?

   (b) Assuming effective masses of electron and holes are equal to free electron mass, calculate E_g and E_F.

   (c) Donor impurities are then added to a concentration of $5 \times 10^{22}\ m^{-3}$. What are the new values for the four quantities calculated above?

3. Using the hydrogenic model, how much energy is required to ionize a donor atom in a semiconductor with dielectric constant of 10 and an electron effective mass that is only 30% of free electron mass. Using the above model, what would the Bohr radius of the donor atom be? At what concentration of donors would there be appreciable overlap of the donor levels to form a band?

4. A Si sample has been doped with $10^{15}\ cm^{-3}$ P atoms. The donor level for P in Si is 0.045 eV below conduction band edge.

   (a) Where is the Fermi level located at 0 K?

   (b) At what temperature is the donor 1 % ionized? Where is the Fermi level located at this temperature?

   (c) At what temperature does the Fermi level lie in the donor energy level?

(d) Estimate the temperature when the sample behaves as if intrinsic.

(e) Sketch schematically the change in Fermi level with temperature.

Take the DOS at conduction and valence band edge to be $10^{19}\ cm^{-3}$ and independent of temperature. The DOS at donor level is $5 \times 10^{14}\ cm^{-3}$. Si band gap is 1.10 eV and independent of temperature.

5. An n-type Si sample has been doped with 10^{17} P atoms cm^{-3}. The drift mobilities of holes and electrons in Si at 300 K depend on the total dopant concentration (N_{dopant}) as follows

$$\mu_e = 88 + \frac{1252}{1 + 6.984 \times 10^{-18}\ N_{dopant}}\ cm^2V^{-1}s^{-1}$$

$$\mu_h = 54.3 + \frac{407}{1 + 3.745 \times 10^{-18}\ N_{dopant}}\ cm^2V^{-1}s^{-1}$$

(a) Calculate the room temperature conductivity.

(b) Calculate the necessary acceptor doping that is required to make this sample p-type with approximately the same conductivity.