ECE 3040
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Homework 2

Unless otherwise specified, assume room temperature (T = 300K) and use the material parameters found in Chapter 2 of Pierret.

1) Purpose: Understanding what the Fermi distribution is telling us.
Consider an energy state in a semiconductor that is 0.2 eV above the Fermi energy level ($E - E_F = 0.2$ eV).
   a) At T = 0K, what is the probability that the energy state is occupied?
   b) At T = 300K (room temperature), what is the probability that the energy state is occupied?
   c) At T = 500K, what is the probability that the energy state is occupied?
   d) What is the trend observed in parts (a)-(c)?

2) Purpose: Understanding the electron distribution in the conduction band.
Consider a semiconductor with a Fermi level that lays 4kT below the conduction band. Assume the sample is held at room temperature. Which of the following energy levels holds more free electrons?
A) $E_1 = E_C + 1/2kT$
B) $E_2 = E_C + 10kT$
Explain.

3) Purpose: Understanding special cases of doping.
Concentration questions with a twist.
   a) At room temperature, the electron concentration in a piece of silicon is 10^{16} cm^{-3}. What is the hole concentration?
   b) For a silicon sample maintained at room temperature, the Fermi level is 5kT below the intrinsic Fermi level. What are the carrier concentrations?
   c) A silicon wafer is doped with $N_A = 10^{16}$ cm^{-3} and $N_D = 10^{17}$ cm^{-3}. At T = 0K, what are the equilibrium electron and hole concentrations?
   d) At elevated temperatures, a silicon wafer has carrier concentrations $n = p = 10^{18}$ cm^{-3}. What would be the dopant concentration?
   e) Knowing that the bandgap of Ge is 0.67 eV. The effective masses of electrons and holes in Ge are $0.55m_0$ and $0.37m_0$. Calculate the intrinsic carrier concentration of Ge.

Hint: Be careful with units for energy calculations.

4) Purpose: Understanding the energy band diagram.
Draw the energy band diagram of a hypothetical semiconductor with the following properties:
   - T = 300K
   - $m_n^* = 0.5m_0$
   - $m_p^* = 0.4m_0$
   - $E_G = 1.1$ eV

- $n = 5 \times 10^{13}$ cm^{-3}

On your diagram, label E_G, E_C, E_V, E_F and E_i and note their values.
Hint: Do not assume that E_i is at mid-gap.

5) Purpose: Understanding of electron-hole relationships.
Consider a piece of silicon held at room temperature. For the various doping conditions, find the hole and electron concentrations, the Fermi level, and note whether the sample is n-type or p-type. Assume total ionization of dopants.
a) 10^{16} cm^{-3} P
b) 10^{16} cm^{-3} P and 10^{17} cm^{-3} B
c) 10^{12} cm^{-3} As and 9×10^{11} cm^{-3} B
Hint: Sections 2.5.5 and 2.5.6 in Pierret may be helpful.

6) Purpose: Understanding partial ionization.
Find the electron and hole concentrations as well as the Fermi level position for a silicon sample with the following conditions.
a) If a Si sample is doped with 10^{20}cm^{-3} P impurities, find the ionized donor density T =300K. For P in Si E_C-E_{donor}=0.045eV.
b) Why is P a more commonly used donor than As?
Hints:
You must use the partial ionization equation from lecture 6 and utilize an iterative technique to find the Fermi level that most closely allows the difference between free electrons and ionized donors to equal the difference between holes and ionized acceptors.
Recall:

$$p - \frac{N_A}{1 + g_A e^{\frac{E_A - E_F}{kT}}} = n - \frac{N_D}{1 + g_D e^{\frac{E_F - E_D}{kT}}}$$

And

$$p = N_V e^{\frac{E_V - E_F}{kT}}$$
$$n = N_C e^{\frac{E_F - E_C}{kT}}$$

In essence, select a Fermi level as a starting point, and use Excel or MATLAB to calculate the free electron concentration, ionized donor concentration, hole concentration, and ionized acceptor concentration from the specific Fermi level and the binding energies of the dopants (which can be found in Table 2.3). Determine if the left- and right-hand sides of the partial ionization equation equal each other (they almost certainly won't on your first attempt). Select another Fermi level position to try to get the left- and right-hand sides of the partial ionization equation to more closely equate. Repeat until you are satisfied with your accuracy. A table of values will greatly help you visualize the trends in your Fermi level guesses and help you make an educated subsequent guess.