ELEN 370-501 Electronic Properties of Materials

Homework #4

Due on 4/10

1. (1) Draw conduction band (CB) and valence band (VB) with electron filling condition for copper (conductor), silicon (semiconductor), and quartz (insulator) at T=0K and T=300K.

(2) What is the conductivity of these three materials under the two temperatures? Provide your explanation based on the band diagram.

(3) Explain the difference in the conductivity of silicon and quartz based on their band gap.

2. Consider a 1D crystal lattice whose lattice distance is \( a \). The energy of electrons in conduction band is \( E_c = \frac{\hbar^2 k^2}{3m_0} + \frac{\hbar^2 k_i^2}{m_0} \). The energy of electrons in valence band is \( E_v = \frac{\hbar^2 k_i^2}{6m_0} - 3\frac{\hbar^2 (k - k_i)^2}{m_0} \). \( m_0 \) is the mass of electron and \( \hbar \) is Planck’s constant. \( k_i = \frac{1}{a} \).

You do not need to plug in the real number. Express your answer in terms of \( m_0, a, \) and \( \hbar \).

(1) Find the location and energy at bottom of conduction band (\( E_{c,\text{min}} \)) and calculate effective mass of electrons (\( m_e^* \)) there; **Hint:** Find minimum or maximum using \( \frac{\partial E}{\partial k} = 0 \).

(2) Find the location and energy at the top of valence band (\( E_{v,\text{max}} \)) and calculate effective mass of holes (\( m_h^* \)) there; **Hint:** At T>0K, some electrons originally in the valence band can obtain enough energy to “jump” into the conduction band, which creates “holes” in the valence band. The \( E_v \) given in this problem is for the electrons, which will render a negative effective mass for the holes. Due to its positive charge, the potential energy for the “holes” should be -\( E_v \).

(3) If the Fermi level (\( E_F \)) is at the center of band gap (\( E_{c,\text{min}} - E_{v,\text{max}} \)), find out \( E_F \).


4. Problem 8.8 (question (i) and (ii) only). The parameters needed for the calculation is listed on the right column.

**Note:** \( N_e \) and \( N_h \) are strongly dependent on temperature (T). If T increases, more electrons will obtain higher energy to “jump” into CB, creating more free electrons in CB and holes in VB, which results in higher conductivity. The decrease of T will have opposite effects. The fluctuation in \( N_e \) and \( N_h \) will affect the operation of the transistors. This explains why every electronics product has a specific working temperature range.
5. A silicon sample contains $10^{16}$ cm$^{-3}$ of phosphorous. Later, it is doped with $2 \times 10^{17}$ cm$^{-3}$ of boron. At this time, both phosphorous and boron atoms coexist in the silicon sample. Suppose $N_i = 1.5 \times 10^{10}$ cm$^{-3}$, $T = 300$K, and $E_g = 1.1$eV.

(1) What type of semiconductor is this silicon sample before the boron doping? Why?

(2) Calculate $N_e$ and $N_h$ before the boron doping;

(3) Determine the difference between the extrinsic and intrinsic Fermi levels before the boron doping;

(4) What type of semiconductor is this silicon sample after the boron doping? Why?

(5) Calculate $N_e$ and $N_h$ after the boron doping;

(6) Determine the difference between the extrinsic and intrinsic Fermi levels after the boron doping;