Homework #3

Thermal Equilibrium and Carrier Transport – *100 points*

DUE @ Beginning of Class: Thursday, September 21

1) Answer the following questions, showing your work where needed: (14 points)

a) A Si wafer is uniformly doped *p*-type with $N_a = 10^{15}$ cm^{-3}. At T = 0 K, what are the equilibrium hole and electron concentrations?

b) A semiconductor is doped with an impurity concentration N such that $N >> n_i$ and all the impurities are ionized. Also, $n_0 = N$ and $p_0 = n_i^2/N$. Is the impurity a donor or an acceptor? Explain.

c) The electron concentration in a piece of Si maintained at 300 K under equilibrium conditions is 10^5 cm^{-3}. What is the hole concentration?

d) For a silicon sample maintained at T = 300 K, the Fermi level is located 0.0259 eV above the intrinsic Fermi level. What are the hole and electron concentrations?

e) In a nondegenerate germanium sample maintained under equilibrium conditions near room temperature, it is known that $n_i = 10^{13}$ cm^{-3}, $n_0 = 2p_0$, and $N_a = 0$. Determine n_0 and N_d.

2) For each of the following conditions, determine the position of E_{Fi}, compute $E_F - E_{Fi}$, and draw a carefully dimensioned energy band diagram (for instance, use graph paper) for the Si sample. Assume temperature independence for effective mass and use $m_p^* = 0.81m_0$ and $m_n^* = 1.18m_0$. NOTE: E_g (Si) = 1.08 eV at 450 K and 1.015 eV at 650 K. (20 points)

a) T = 300 K, $N_a << N_d$, $N_d = 10^{15}$ cm^{-3}

b) T = 300 K, $N_a = 10^{16}$ cm^{-3}, $N_d << N_a$

c) T = 300 K, $N_a = 9 \times 10^{15}$ cm^{-3}, $N_d = 10^{16}$ cm^{-3}

d) T = 450 K, $N_a = 0$, $N_d = 10^{14}$ cm^{-3}

e) T = 650 K, $N_a = 0$, $N_d = 10^{14}$ cm^{-3}

3) E-Book, problem 4.17 (9 points)

4) E-Book, problem 4.26 (12 points)

5) E-Book, problem 4.34 (20 points)

6) E-Book, problem 4.47 (5 points)

7) E-Book, problem 4.55 (10 points)

8) E-Book, problem 4.62 (10 points)

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3) E-Book, problem 4.17 (9 points)

4.17 Silicon at $T = 300$ K is doped with arsenic atoms such that the concentration of electrons is $n_0 = 7 \times 10^{15}$ cm^{-3}. (*a*) Find $E_c - E_F$. (*b*) Determine $E_F - E_v$. (*c*) Calculate p_0. (*d*) Which carrier is the minority carrier? (*e*) Find $E_F - E_{Fi}$.

4) E-Book, problem 4.26 (12 points)

4.26 (*a*) Determine the values of n_0 and p_0 in GaAs at $T = 300$ K if $E_F - E_v = 0.25$ eV. (*b*) Assuming the value of p_0 in part (*a*) remains constant, determine the values of $E_F - E_v$ and n_0 at $T = 400$ K.

5) E-Book, problem 4.34 (20 points)

4.34 Determine the equilibrium electron and hole concentrations in silicon for the following conditions:

(*a*) $T = 300$ K, $N_d = 10^{15}$ cm^{-3}, $N_a = 4 \times 10^{15}$ cm^{-3}

(*b*) $T = 300$ K, $N_d = 3 \times 10^{16}$ cm^{-3}, $N_a = 0$

(*c*) $T = 300$ K, $N_d = N_a = 2 \times 10^{15}$ cm^{-3}

(*d*) $T = 375$ K, $N_d = 0$, $N_a = 4 \times 10^{15}$ cm^{-3}

(*e*) $T = 450$ K, $N_d = 10^{14}$ cm^{-3}, $N_a = 0$

6) E-Book, problem 4.47 (5 points)

4.47 In silicon at $T = 300$ K, it is found that $N_a = 7 \times 10^{15}$ cm^{-3} and $p_0 = 2 \times 10^4$ cm^{-3}. (*a*) Is the material n type or p type? (*b*) What are the majority and minority carrier concentrations? (*c*) What must be the concentration of donor impurities?

7) E-Book, problem 4.55 (10 points)

4.55 (*a*) Silicon at $T = 300$ K is doped with donor impurity atoms at a concentration of $N_d = 6 \times 10^{15}$ cm^{-3}. (*i*) Determine $E_c - E_F$. (*ii*) Calculate the concentration of additional donor impurity atoms that must be added to move the Fermi energy level a distance kT closer to the conduction band edge. (*b*) Repeat part (*a*) for GaAs if the original donor impurity concentration is $N_d = 1 \times 10^{15}$ cm^{-3}.

8) E-Book, problem 4.62 (10 points)

4.62 Silicon atoms, at a concentration of 7×10^{15} cm^{-3}, are added to gallium arsenide. Assume that the silicon atoms act as fully ionized dopant atoms and that 5 percent of the concentration added replace gallium atoms and 95 percent replace arsenic atoms. Let $T = 300$ K. (*a*) Determine the donor and acceptor concentrations. (*b*) Is the material n type or p type? (*c*) Calculate the electron and hole concentrations. (*d*) Determine the position of the Fermi level with respect to E_{Fi}.