ECE 3030 Spring 2025 HOMEWORK ASSIGNMENT NO. 3

Due: Monday, February 3th 11:59 pm upload to Carmen 3030 SpeedGrader

1. (10 pt) Using the Fermi function, determine the probability that an energy level is occupied by an electron if the state is above the Fermi level by (a) kT, (b) 4 kT, and (c) 9 kT. For (a), what is the probability that the energy level is unoccupied?

2. (25 pt) 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) Using the result in (b), calculate p_0. (d) Which carrier is the minority carrier? (e) Find $E_F - E_i$. For Si, use $E_G = 1.12$ eV, $n_i = 1.5 \times 10^{10}$ cm^{-3}, $N_C = 2.8 \times 10^{19}$ cm^{-3} and $N_V = 1.04 \times 10^{19}$ cm^{-3}. Show your work.

3. (20pt) 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}

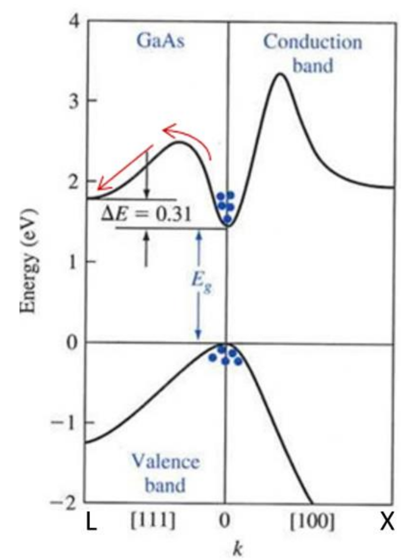
   (b) T = 300 K, $N_d = 3 \times 10^{16}$ cm^{-3}, $N_a = 0$

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

   (d) T = 375 K, $N_d = 0$, Na = 4×10^{15}cm^{-3}

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

4. (15 pt) (a) Determine the concentration of donor impurity atoms that must be added to a Si crystal so that the Fermi level is 0.20 eV below the conduction band edge. The Si band gap is 1.11 eV and $n_i = 1.5 \times 10^{10}$ cm^{-3}, (b) Suppose that the Si crystal already has 10^{16} cm^{-3} acceptor impurity concentration. What concentration of donors must be added now to achieve the same result?



5. (15 pt) Since the effective mass of electrons in a conduction band decreases with increasing band curvature, comment on the electron effective mass in the Γ valley of GaAs compared with the indirect X or L valleys. How is this effective mass difference reflected in the electron mobility for GaAs vs. the indirect X valley electron mobility in GaP (see Appendix III, S&B.) What would you expect to happen to the conductivity of GaAs if Γ-valley electrons drifting in an electric field were suddenly promoted to the L valley?

6. (15 pt) A 2 cm long piece of Si with cross –sectional area of 0.1 cm^2 is doped with donors at 10^{15} cm^{-3} and has a resistance of 90 ohms. The saturation velocity of electrons in Si is 10^7 cm/s for fields above 10^5 V/cm. Calculate the electron drift velocity if we apply a voltage of 100 V across the piece. What is the current through the piece if we apply a voltage of 100 V across it? What is the current for 200V? What about 10^6 V? Is current still proportional to applied voltage?

10 Point Bonus: The maximum intrinsic carrier concentration in a silicon device must be limited to 5×10^{11} cm^{-3} thermally stimulated carriers. Assume $E_g = 1.12$ eV. Determine the maximum temperature allowed for the device. (b) Repeat part (a) if the maximum intrinsic carrier concentration is limited to 5×10^{12} cm^{-3}. Hint: Trial and error temperatures needed. Show your work.