# VE320 Homework 3

1. (a) The carrier effective masses in a semiconductor are $m_n^* = 1.21\, m_0$ and $m_p^* = 0.70\, m_0$. Determine the position of the intrinsic Fermi level with respect to the center of the bandgap at $T = 300$ K. (b) Repeat part (a) if $m_n^* = 0.080\, m_0$ and $m_p^* = 0.75\, m_0$.

2. Silicon at $T = 300$ K is doped with boron atoms such that the concentration of holes is $p_0 = 5 \times 10^{15}$ cm$^{-3}$. (a) Find $E_F - E_v$. (b) Determine $E_c - E_F$. (c) Determine $n_0$. (d) Which carrier is the majority carrier? (e) Determine $E_{Fi} - E_F$.

3. (a) Consider a germanium semiconductor at $T = 300$ K. Calculate the thermal equilibrium electron and hole concentrations for (i) $N_d = 2 \times 10^{15}$ cm$^{-3}$, $N_a = 0$, and (ii) $N_a = 10^{16}$ cm$^{-3}$, $N_d = 7 \times 10^{15}$ cm$^{-3}$. (b) Repeat part (a) for GaAs. (c) For the case of GaAs in part (b), the minority carrier concentrations are on the order of $10^{-3}$ cm$^{-3}$. What does this result mean physically?

4. (a) Silicon at $T = 300$ K is uniformly doped with boron atoms to a concentration of $3 \times 10^{16}$ cm$^{-3}$ and with arsenic atoms to a concentration of $1.5 \times 10^{16}$ cm$^{-3}$. Is the material n type or p type? Calculate the thermal equilibrium concentrations of majority and minority carriers. (b) Additional impurity atoms are added such that holes are the majority carrier and the thermal equilibrium concentration is $p_0 = 5 \times 10^{16}$ cm$^{-3}$. What type and concentration of impurity atoms must be added? What is the new value of $n_0$?

5. A silicon device is doped with donor impurity atoms at a concentration of $10^{15}$ cm$^{-3}$. For the device to operate properly, the intrinsic carriers must contribute no more than 5 percent to the total electron concentration. (a) What is the maximum temperature that the device may operate? (b) What is the change in $E_c - E_F$ from the $T = 300$ K value to the maximum temperature value determined in part (a). (c) Is the Fermi level closer or further from the intrinsic value at the higher temperature?

6. For a particular semiconductor, $E_g = 1.50$ eV, $m_p^* = 10\, m_n^*$, $T = 300$ K, and $n_i = 1 \times 10^5$ cm$^{-3}$. (a) Determine the position of the intrinsic Fermi energy level with respect to the center of the bandgap. (b) Impurity atoms are added so that the Fermi energy level is 0.45 eV below the center of the bandgap. (i) Are acceptor or donor atoms added? (ii) What is the concentration of impurity atoms added?

7. Silicon atoms, at a concentration of $7 \times 10^{15}$ 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 $E_{Fi}$.

8. A silicon crystal having a cross-sectional area of 0.001 cm² and a length of $10^{-3}$ cm is connected at its ends to a 10-V battery. At $T = 300$ K, we want a current of 100 mA in the silicon. Calculate (a) the required resistance R, (b) the required conductivity, (c) the density of donor atoms to be added to achieve this conductivity, and (d) the concentration of acceptor atoms to be added to form a compensated p-type material with the conductivity given from part (b) if the initial concentration of donor atoms is $N_d = 10^{15}$ cm⁻³.

9. (a) A silicon semiconductor resistor is in the shape of a rectangular bar with a cross-sectional area of $8.5 \times 10^{-4}$ cm², a length of 0.075 cm, and is doped with a concentration of $2 \times 10^{16}$ cm⁻³ boron atoms. Let $T = 300$ K. A bias of 2 volts is applied across the length of the silicon device. Calculate the current in the resistor. (b) Repeat part (a) if the length is increased by a factor of three. (c) Determine the average drift velocity of holes in parts (a) and (b).

10. If there is four electrons located in an infinite quantum with a width of a=1 nanometer ($10^{-9}$m). In the following figure (a) please use black dots to represent the E-k relation of the four electrons. In the following figure (b) and (c), please plot $\Psi(x)$ and $\Psi(x)\Psi(x)^*$.
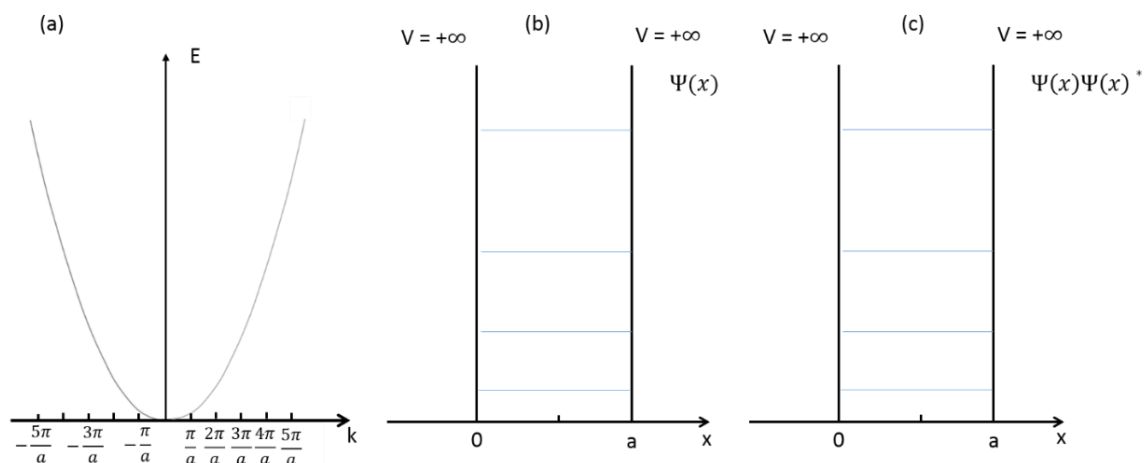


11. What kind of energy band structures will metals and semiconductors have? At absolute zero temperature, why metals are electrically conducting and semiconductors are not conducting?