ECSE-2210 Microelectronics Technology
Class Activity 5 – Solution

Assume $T = 300$ K for all your calculations. Assume $n_i = 10^{10}$ cm^{-3} at 300 K for Si.

1) Explain what "degenerate" and "non-degenerate" semiconductors mean.
   Non-degenerate means that the Fermi level lies in the band gap such that
   $E_C - 3kT > E_F > E_V + 3kT$

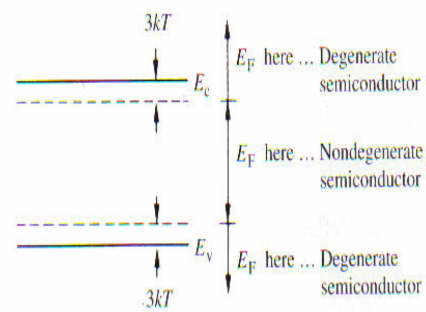


Figure 2.19 Definition of degenerate/nondegenerate semiconductors.

   When E_F lies in the band gap closer than 3kT to either band edge or actually lies in the band, the semiconductor is said to be degenerate. Degenerate indicates that the semiconductor is very heavily doped.

2) Calculate the numerical value of the following integral (assume Si contains 10^{15} cm^{-3} electrons in its conduction band). It should not take more than 30 seconds to answer this.

$$\int_{E_{C,\text{ bottom}}}^{E_{C,\text{ top}}} g_c(E) f(E) dE$$

   What will be the number of holes/cm^3 in Si?
   The integral represents the total number of electrons in the conduction band, i.e., 10^{15} cm^{-3}.
   The number of holes is $p = 10^5$ cm^{-3}. [$np = n_i^2$ so, $p = n_i^2/n = 10^5$cm^{-3}.]

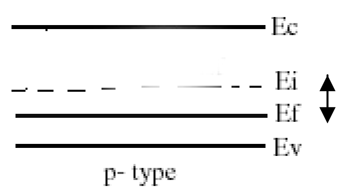
3) For a silicon sample maintained at T = 300K, the number of electrons in the conduction band, (i.e., n) is 1×10^{16}cm^{-3}. Calculate the number of holes in the valence band (i.e., p). Also, draw the band diagram (i.e., mark the position of the Fermi-level, E_F, and E_C, E_V, and E_i).

   The number of holes is $np = n_i^2$ so, $p = n_i^2/n = (10^{20}/10^{16})$ cm^{-3} = 10^4 cm^{-3}.
   $E_F - E_I = kT \ln(10^{16}/10^{10})$. This means that E_F is 0.353 eV above E_i

4) For a semiconductor (not Si) with a band gap 1 eV, the n and p values are 1×10^{16} cm^{-3} and 1×10^{6} cm^{-3}, respectively. Is the semiconductor n-type or p-type? What will be the intrinsic carrier concentration for this semiconductor?
N-type since $n > p$. $n_i = (np)^{1/2} = 10^{11}$ cm^{-3}.

5) A Si wafer is uniformly doped with 2×10^{17} cm^{-3} of Phosphorous and 4×10^{17} cm^{-3} of Boron. Assuming full ionization, calculate the following quantities at room temperature ($T = 300$ K).
   (a) The equilibrium hole concentration, p. (start with the charge-neutrality condition).
   $p = N_A - N_D = 2 \times 10^{17}$cm^{-3}.
   (Use the full charge balance equation: $p + N_D = n + N_A$.)
   Note that the phosphorous concentration is N_D and the boron concentration is N_A
   (b) The equilibrium electron concentration, n.
   $N = n_i^2/p = 10^{20}/(2 \times 10^{17})$ cm^{-3} = 500 cm^{-3}

   (c) The position of the Fermi level (E_F) relative to the intrinsic level (E_i). Draw the band diagram show these to levels.
   $p = n_i \times \exp[(E_i - E_F) / kT]$
   $2 * 10^{17} = 10^{10} * \exp[(E_i - E_F) / kT]$
   $(E_i - E_F) = 0.435$ eV



   (d) Which one of the above three quantities (p, n) has the strongest temperature dependence near 300 K? Explain.
   n since it is n_i^2/p. p does not vary, but n_i increases exponentially with increasing T.

   (e) Suppose you now add 1×10^{13} cm^{-3} of Arsenic to the Si sample. What will be the equilibrium concentration of holes (p) at 300 K? (Don't have to go through the whole math again. Make an educated guess with justification).
   No change since 10^{13} cm^{-3} is small compared to 2×10^{17} cm^{-3} of Phosphorous. Since the order of Arsenic that is added is 4 orders of magnitude less than that of phosphorous there is no significant change in the equilibrium concentration of holes.