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Faculty of Engineering
Electrical Engineering Department

ECE 336: Semiconductor Devices
Sheet 1

Chapter 2:

1- Using the energy band model for a semiconductor, indicate how one visualizes (a) an electron, (b) a hole, (c) donor sites, (d) acceptor sites, (e) Freeze out of majority carrier electrons at donor sites as the temperature is lowered toward 0 K (f)) Freeze out of majority carrier holes at acceptor sites as the temperature is lowered toward 0 K , (g) Energy distribution of carriers in the respective bands, (h) an intrinsic semiconductor, (i) n-type semiconductor, (j) p-type semiconductor, (k) a non-degenerate semiconductor, (l) a degenerate semiconductor.

2- Develop an expression for the total number of available STATES/cm^3 in the conduction band between energies E_c and $E_c + \gamma KT$, where γ is an arbitrary constant.

3- (a) Under equilibrium conditions and T>0K, what is the probability of an electron state being occupied if it is located at the Fermi level?
(b) If E_F is positioned at E_C, determine (numerical answer required) the probability of finding electrons in statesat E_C+KT?
(c) The probability a slate is filled at E_C+KT equal to the probability a state is empty at E_C+KT, where is that Fermi level?

4- The carrier distributions or numbers of carriers as a function of energy in the conduction and valence bands were noted to be peak at an energy very close to band edges. Taking the semiconductor to be non-degenerate, show that the energy at which the carrier distribution peak is E_C+KT/2 and E_v = KT/2 for the conduction and valence bands, respectively.

5- For a non-degenerate semiconductor, the peak in the electron distribution versus energy inside the conduction band noted in Figure 2.16 occurs at E_c + KT/2. Expressed as a fraction of the electron population at the peak energy, what is the electron population in a non-degenerate semiconductor at E = E_C + 5KT?

6- The Fermi Level in Si sample maintained at T = 300 K is located at $E_c - E_G/4$, compute and plot the electron and hole distributions as a function of energy in the conduction and valence bands respectively.

7- Let us investigate how the electron energy distribution in the conduction band varies as a function of temperature.
   a. Assuming the semiconductor to be non-degenerate and employing equation 2.16a expression for n, confirm that the electron distribution in the conduction band normalized to the total electron concentration given by $$\frac{g_c(E)f(E)}{n} = \frac{2\sqrt{E-E_C}}{\sqrt{\pi}\,(kT)^{3/2}}\, e^{-(E-E_C)/kT}$$

b. Compute and plot the normalized electron distribution in the conduction band versus $E - E_c$ for temperatures T = 300k, 600K and 1200K. Plot the distribution values along the x-axis ($0 <= g_c(E)f(E)/n <= 20\ eV^{-1}$) and $E - E_c$($0<= E-E_c <= 0.4eV$) along the y-axis on a single set of coordinates, discuss your results.

8- The density of states in the conduction band of a hypothetical semiconductor is $g_c(E)$ = constant = N_C/kT … $E>= E_c$

a. Assuming $E_F < E_c - 3kT$, sketch the electron distribution in the conduction band of the hypothetical semiconductor.
b. Following the procedure outlined in the text, establish relationships for the electron concentration in the hypothetical semiconductor analogous to equations 2.14a and 2.16a.

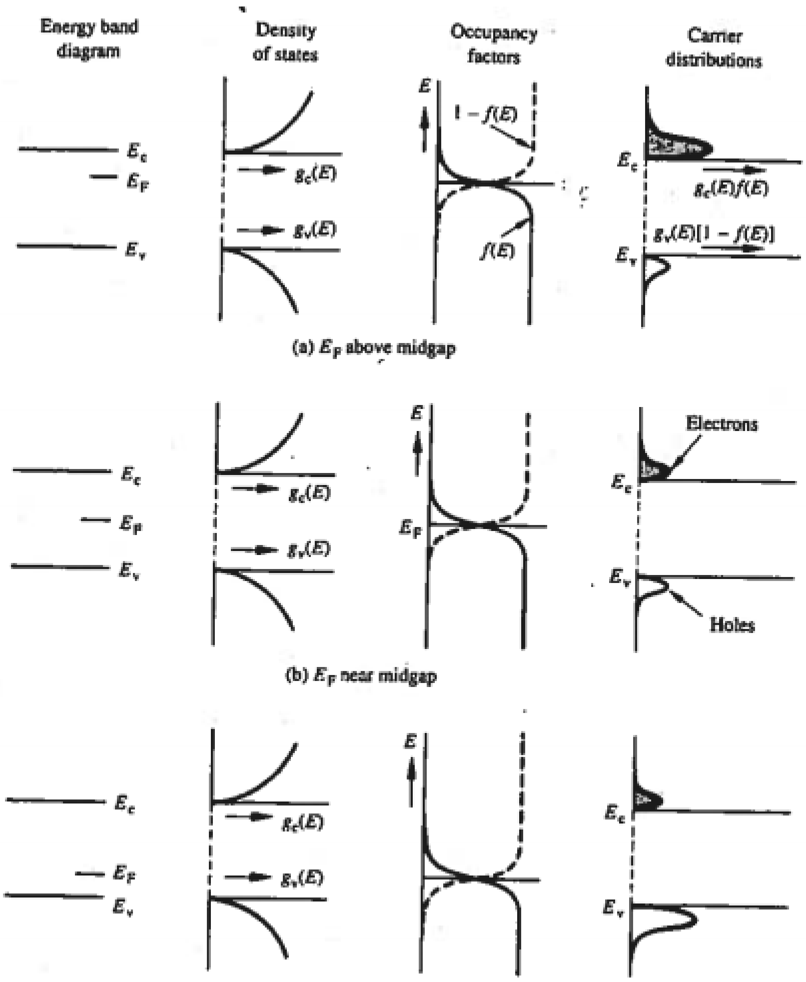
9- Concentration questions with a twist

a. A silicon wafer uniformly doped p-type with $N_A = 10^{15}\ cm^{-3}$. At T = 0K. 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 =N and $p =n_i^2/N$. Is the impurity a donor or acceptor? Explain.
c. The electron concentration in a piece of Si maintained at 300K under equilibrium conditions is $10^{15}\ cm^{-3}$ .What is the hole concentration?
d. For a silicon sample maintained at T=300K, the Fermi level is located 0.259eV above the intrinsic Fermi level. What are the hole and eleclron concentrations?
e. In a non-degenerate germanium sample maintained under equilibrium conditions near room temperature, it is known that $n_i =10^{13}\ cm^{-3}$, n = 2p, and N_A=0. Determine n and N_D.

10- Determine the electron and hole concentration inside a uniformally doped sample of Si under the following conditions.

a. T = 300K, $N_A << N_D$, $N_D = 10^{15}\ cm^{-3}$.
b. T = 300K, $N_D << N_A$, $N_A = 10^{16}\ cm^{-3}$.
c. T = 300K, $N_A = 9x10^{15}\ cm^{-3}$, $N_D = 10^{16}\ cm^{-3}$.
d. T = 450K, $N_A = 0$, $N_D = 10^{14}\ cm^{-3}$.
e. T = 650K, $N_A = 0$, $N_D = 10^{14}\ cm^{-3}$.

Figure 2.16



Equations 2.16

$$n = N_C e^{(E_F - E_c)/kT}$$

$$p = N_V e^{(E_v - E_F)/kT}$$

Equations 2.14

$$n = N_C \frac{2}{\sqrt{\pi}} F_{1/2}(\eta_c)$$

$$p = N_V \frac{2}{\sqrt{\pi}} F_{1/2}(\eta_v)$$