Ve320 Introduction of Semiconductor Device

Homework 3

Due Date: June. 13th

Ex.1

(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?

Ex.2

(a) Silicon at $T = 300$ K is uniformly doped with boron atoms to a concentration of 3×10^{16} cm^{-3} and with arsenic atoms to a concentration of 1.5×10^{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?

Ex.3

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?

Ex.4

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?

Ex.5

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}.

Ex.6

A silicon crystal having a cross-sectional area of 0.001 cm^2 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}.

Ex.7

(*a*) A silicon semiconductor resistor is in the shape of a rectangular bar with a cross-sectional area of 8.5×10^{-4} cm^2, a length of 0.075 cm, and is doped with a concentration of 2×10^{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*).

Ex.8

(*a*) Assume that the electron mobility in an n-type semiconductor is given by

$$\mu_n = \frac{1350}{\left(1 + \dfrac{N_d}{5 \times 10^{16}}\right)^{1/2}} \text{ cm}^2/\text{V-s}$$

where N_d is the donor concentration in cm^{-3}. Assuming complete ionization, plot the conductivity as a function of N_d over the range $10^{15} \le N_d \le 10^{18}$ cm^{-3}. (*b*) Compare the results of part (*a*) to that if the mobility were assumed to be a constant equal to 1350 cm^2/V-s. (*c*) If an electric field of $E = 10$ V/cm is applied to the semiconductor, plot the electron drift current density of parts (*a*) and (*b*).

Ex.9

A constant electric field, E = 12 V/cm, exists in the $+x$ direction of an n-type gallium arsenide semiconductor for $0 \le x \le 50$ μm. The total current density is a constant and is $J = 100$ A/cm^2. At $x = 0$, the drift and diffusion currents are equal. Let $T = 300$ K and $\mu_n = 8000$ cm^2/V-s. (*a*) Determine the expression for the electron concentration $n(x)$. (*b*) Calculate the electron concentration at $x = 0$ and at $x = 50$ μm. (*c*) Calculate the drift and diffusion current densities at $x = 50$ μm.

Ex.10

Consider an n-type semiconductor at $T = 300$ K in thermal equilibrium (no current). Assume that the donor concentration varies as $N_d(x) = N_{d0}e^{-x/L}$ over the range $0 \le x \le L$ where $N_{d0} = 10^{16}$ cm^{-3} and $L = 10$ μm. (*a*) Determine the electric field as a function of x for $0 \le x \le L$. (*b*) Calculate the potential difference between $x = 0$ and $x = L$ (with the potential at $x = 0$ being positive with respect to that at $x = L$).