VE320 Homework 3

Due Oct. 8, 23:59pm

1. (a) For silicon, find the ratio of the density of states in the conduction band at $E=Ec+kT$ to the density of states in the valence band at $E=Ev-kT$. (b) Repeat part (a) for GaAs.
2. (a) The Fermi energy in silicon is $0.30eV$ below the conduction band energy E_c at $T=300K$. Plot the probability of a state being occupied by an electron in the conduction band over the range $E_c \leqslant E \leqslant E_c+2kT$. (b) The Fermi energy in silicon is $0.25eV$ above the valence band energy E_v. Plot the probability of a state being empty by an electron in the valence band over the range $E_v-2kT \leqslant E \leqslant E_v$.
3. (a) Calculate the temperature at which there is a 10^{-8} probability that an energy state $0.60eV$ above the Fermi energy level is occupied by an electron. (b) Repeat part (a) for a probability of 10^{-6}.
4. (*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 $m_p^* = 0.75\ m_0$.
5. 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 $E_{Fi} - E_F$.
6. (*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?
7. (*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?
8. 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?
9.

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?

10.

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}.

11.

Consider a semiconductor that is uniformly doped with $N_d = 10^{14}$ cm^{-3} and $N_a = 0$, with an applied electric field of E = 100 V/cm. Assume that $\mu_n = 1000$ cm^2/V-s and $\mu_p = 0$. Also assume the following parameters:

$$N_c = 2 \times 10^{19}\,(T/300)^{3/2} \text{ cm}^{-3}$$
$$N_v = 1 \times 10^{19}\,(T/300)^{3/2} \text{ cm}^{-3}$$
$$E_g = 1.10 \text{ eV}$$

(*a*) Calculate the electric-current density at $T = 300$ K. (*b*) At what temperature will this current increase by 5 percent? (Assume the mobilities are independent of temperature.)

12.

The effective density of states functions in silicon can be written in the form

$$N_c = 2.8 \times 10^{19}\left(\frac{T}{300}\right)^{3/2} \qquad N_v = 1.04 \times 10^{19}\left(\frac{T}{300}\right)^{3/2}$$

Assume the mobilities are given by

$$\mu_n = 1350\left(\frac{T}{300}\right)^{-3/2} \qquad \mu_p = 480\left(\frac{T}{300}\right)^{-3/2}$$

Assume the bandgap energy is $E_g = 1.12$ eV and independent of temperature. Plot the intrinsic conductivity as a function of T over the range $200 \le T \le 600$ K.

13.

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 $x = L$).

14.

Consider a semiconductor at $T = 300$ K. (*a*) (*i*) Determine the electron diffusion coefficient if the electron mobility is $\mu_n = 1150$ cm^2/V-s. (*ii*) Repeat (*i*) of part (*a*) if the electron mobility is $\mu_n = 6200$ cm^2/V-s. (*b*) (*i*) Determine the hole mobility if the hole diffusion coefficient is $D_p = 8$ cm^2/s. (*ii*) Repeat (*i*) of part (*b*) if the hole diffusion coefficient is $D_p = 35$ cm^2/s.

15.

The steady-state electron distribution in silicon can be approximated by a linear function of x. The maximum electron concentration occurs at $x = 0$ and is $n(0) = 2 \times 10^{16}$ cm^{-3}. At $x = 0.012$ cm, the electron concentration is 5×10^{15} cm^{-3}. If the electron diffusion coefficient is $D_n = 27$ cm^2/s, determine the electron diffusion current density.