ECE 336: Semiconductor Devices
Sheet 2

1.
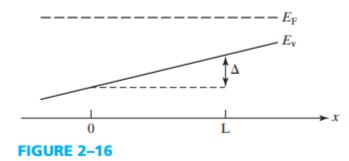   a. For an electron mobility of 500 cm²/V·s, calculate the time between collisions.(Take $m_n = m_0$ in these calculations.)
   b. For an electric field 100 V/cm, calculate the distance an electron travels by drift between collisions.

2. An electron is moving in a piece of very lightly doped silicon under an applied field such that its drift velocity is one-tenth of its thermal velocity. Calculate the average number of collisions it will experience in traversing by drift a region 1 µm long. What is the voltage across this region?

3. Phosphorus donor atoms at a concentration of 10^{16}cm^{-3} are distributed uniformly throughout a silicon sample.
   a. What is the sample resistivity at 300 K?
   b. If 10^{17}cm^{-3} of boron is included in addition to the phosphorus, what is the resulting resistivity and conductivity type(N-type or P-type material)?
   c. Sketch the energy band diagram for part (a) and for part (b) and show the position of the Fermi level.

4. An N-type silicon sample has a uniform density $N_d = 10^{17} \text{cm}^{-3}$ of arsenic, and a P-type sample has $N_a = 10^{15} \text{cm}^{-3}$. A third sample has both impurities present at the same time.
   a. Find the equilibrium minority carrier concentrations at 300 K in each sample.
   b. Find the conductivity of each sample at 300 K.
   c. Find the Fermi level in each material at 300 K with respect to either the conduction band edge (E_c) or the valence band edge (E_v).

5.
   a. A silicon sample maintained at T = 300 K is uniformly doped with $N_d = 10^{16} \text{cm}^{-3}$ donors. Calculate the resistivity of the sample.
   b. The silicon sample of part (a) is "compensated" by adding $N_a = 10^{16} \text{cm}^{-3}$ acceptors. Calculate the resistivity of the compensated sample. (Exercise caution in choosing the mobility values to be employed in this part of the problem.)
   c. Compute the resistivity of intrinsic ($N_a = 0$, $N_d = 0$) silicon at T = 300 K. Compare it with the result of part (b) and comment.

6. A sample of N-type silicon is at the room temperature. When an electric field with a strength of 1000 V/cm is applied to the sample, the hole velocity is measured and found to be 2×10^5 cm/sec.
   a. Estimate the thermal equilibrium electron and hole densities, indicating which is the minority carrier.
   b. Find the position of E_F with respect to E_c and E_v.
   c. The sample is used to make an integrated circuit resistor. The width and height of the sample are 10 µm and 1.5 µm, respectively, and the length

of the sample is 20μm. Calculate the resistance of the sample.

7. A general relationship for the current density carried by electrons of density n is J = qnv, here q is the electronic charge and v is the electron velocity.
   a. Find the velocity of electrons, $v(x)$, that are moving only by diffusion if they have a density distribution of $n(x) = n_0 \exp(-x/\lambda)$. The electric field is zero.
   b. What would be the electric field, $E(x)$, that would lead to an electron drift velocity equal to that of the diffusion velocity in part (a)?
   c. At 300 K, what value of λ would make the field in part (b) to be 1000 V/cm?

8. Figure 2–16 is a part of the energy band diagram of a P-type semiconductor bar under equilibrium conditions (i.e., EFis constant). The valence band edge is sloped because doping is non-uniform along the bar. Assume that E_v rises with a slope of Δ/L.

FIGURE 2–16

   a. Write an expression for the electric field inside this semiconductor bar.
   b. Within the Boltzmann approximation, what is the electron concentration $n(x)$ along the bar? Assume that $n(x=0)$ is n_0. Express your answer in terms of n_0, Δ, and L.
   c. Given that the semiconductor bar is under equilibrium, the total electron and hole currents are individually zero. Use this fact and your answers to parts (a) and (b) to derive the Einstein relation ($D_n/\mu_n = kT/q$) relating electron mobility and diffusion constant.