Solid State Electronics Homework #4 Due 04/15

(Note: Use the semiconductor parameters given in Appendix B if the parameters are not specifically given in a problem.)

4.1 A silicon semiconductor at \( T = 300 \text{ K} \) is homogeneously doped with \( N_d = 5 \times 10^{15} \text{ cm}^{-3} \) and \( N_a = 0 \). (a) Determine the thermal equilibrium concentrations of free electrons and free holes. (b) Calculate the drift current density for an applied \( \varepsilon \)-field of 30 V/cm. (c) Repeat parts (a) and (b) for \( N_d = 0 \) and \( N_a = 5 \times 10^{16} \text{ cm}^{-3} \).

4.3 (a) A silicon semiconductor is in the shape of a rectangular bar with a cross-sectional area of 10 \( \mu \text{m} \times 10 \mu\text{m} \), a length of 0.1 cm, and is doped with \( 5 \times 10^{16} \text{ cm}^{-3} \) arsenic atoms. The temperature is \( T = 300 \text{ K} \). Determine the current if 5 V is applied across the length. (b) Repeat part (a) if the length is reduced to 0.01 cm. (c) Calculate the average drift velocity of electrons in parts (a) and (b).

4.10 (a) Calculate the resistivity at \( T = 300 \text{ K} \) of intrinsic (i) silicon, (ii) germanium, and (iii) gallium arsenide. (b) If rectangular semiconductor bars are fabricated using the materials in part (a), determine the resistance of each bar if its cross-sectional area is 85 \( \mu\text{m}^2 \) and length is 200 \( \mu\text{m} \).

4.12 Consider silicon doped at impurity concentrations of \( N_d = 2 \times 10^{16} \text{ cm}^{-3} \) and \( N_a = 0 \). An empirical expression relating electron drift velocity to electric field is given by

\[
v_d = \frac{\mu_{n0} \varepsilon}{\sqrt{1 + \left( \frac{\mu_{n0} \varepsilon}{v_{\text{sat}}} \right)^2}}
\]

where \( \mu_{n0} = 1350 \text{ cm}^3/\text{V-s} \), \( v_{\text{sat}} = 1.8 \times 10^7 \text{ cm/s} \), and \( \varepsilon \) is given in V/cm. Plot electron drift current density (magnitude) versus electric field (log-log scale) over the range \( 0 \leq \varepsilon \leq 10^6 \text{ V/cm} \).

4.14 Consider a semiconductor that is uniformly doped with \( N_d = 10^{14} \text{ cm}^{-3} \) and \( N_a = 0 \), with an applied electric field of \( \varepsilon = 100 \text{ V/cm} \). Assume that \( \mu_n = 1000 \text{ cm}^2/\text{V-s} \) and \( \mu_p = 0 \). Also assume the follow parameter:

\[
N_c = 2 \times 10^{19} \left( \frac{T}{300} \right)^{3/2} \text{ cm}^{-3}
\]
\[
N_v = 1 \times 10^{19} \left( \frac{T}{300} \right)^{3/2} \text{ cm}^{-3}
\]
\[
E_g = 1.10 \text{ eV}
\]

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

4.17 Three scattering mechanisms are present in a particular semiconductor material. If only the first scattering mechanism were present, the mobility would be \( \mu_1 = 2000 \text{ cm}^2/\text{V-s} \), if only the second mechanism were present, the mobility would be \( \mu_2 = 1500 \text{ cm}^2/\text{V-s} \), and if only the third mechanism were present, the mobility would be \( \mu_3 = 500 \text{ cm}^2/\text{V-s} \). What is the net mobility?

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

\[
N_e = 2.8 \times 10^{19} \left( \frac{T}{300} \right)^{3/2} \quad N_v = 1.04 \times 10^{19} \left( \frac{T}{300} \right)^{3/2}
\]

Assume the mobilities are given by

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

Assume the bandgap energy is \( E_g = 1.12 \text{ eV} \) and independent of temperature. Plot the intrinsic conductivity as a function of \( T \) over the range \( 200 \leq T \leq 500 \text{ K} \).

4.22 Consider a sample of silicon at \( T = 300 \text{ K} \). Assume that the electron concentration varies linearly with distance, as shown in Figure P4.22. The diffusion current density is found to be \( J_n = 0.19 \text{ A/cm}^2 \). If the electron diffusion coefficient is \( D_n = 25 \text{ cm}^2/\text{s} \), determine the electron concentration at \( x = 0 \).

![Figure P4.22](image)

4.29 The hole concentration in germanium at \( T = 300 \text{ K} \) varies as

\[
p(x) = 10^{15} \exp \left( \frac{-x}{22.5} \right) \text{ cm}^{-3}
\]

where \( x \) is measured in \( \mu \text{m} \). If the hole diffusion coefficient is \( D_p = 48 \text{ cm}^2/\text{s} \),
determine the hole diffusion current density as a function of $x$.

4.35 Consider a semiconductor in thermal equilibrium (no current). Assume that the donor concentration varies exponentially as

$$N_d(x) = N_{d0} \exp(-ax)$$

over the range $0 \leq x \leq 1/\alpha$ where $N_{d0}$ is a constant. 

(a) Calculate the electric field as a function of $x$ for $0 \leq x \leq 1/\alpha$. 

(b) Calculate the potential difference between $x = 0$ and $x = 1/\alpha$.

4.41 Arsenic is diffused into an intrinsic silicon sample and has the general profile shown in Figure P4.41. Sketch the equilibrium energy-band diagram. Show the direction of the electric field.

![Figure P4.41](Figure for Problem 4.41)

4.43 Consider a semiconductor in which $n_0 = 10^{15}$ cm$^{-3}$ and $n_i = 10^{10}$ cm$^{-3}$. Assume that the excess carrier lifetime is $10^{-6}$ s. Determine the electron-hole recombination rate if the excess hole concentration is $\delta_p = 5 \times 10^{13}$ cm$^{-3}$.

4.45 An n-type silicon sample contains a donor concentration of $N_d = 10^{16}$ cm$^{-3}$. The minority carrier hole lifetime is found to be $\tau_{p0} = 20$ $\mu$s. 

(a) What is the lifetime of the majority carrier electrons? 

(b) Determine the thermal-equilibrium generation rate for electrons and holes in this material. 

(c) Determine the thermal-equilibrium recombination rate for electrons and holes in this material.

4.47 A sample of silicon is doped with $10^{16}$ boron atoms per cm$^3$. The Hall sample has the same geometrical dimensions given in Example 4.8. The current is $I_x = 1$ mA with $B_z = 350$ gauss = $3.5 \times 10^{-2}$ tesla. Determine (a) the Hall voltage and (b) the Hall field.
4.51 Consider a gallium arsenide sample at $T = 300$ K. A Hall effect device has been fabricated with the following geometry: $d = 0.01$ cm, $W = 0.05$ cm, and $L = 0.5$ cm. The electrical parameters are: $I_x = 2.5$ mA, $V_x = 2.2$ V, and $B_z = 2.5 \times 10^{-2}$ tesla. The Hall voltage is $V_H = -4.5$ mV. Find: (a) the conductivity type, (b) the majority-carrier concentration, (c) the mobility, and (d) the resistivity.

Q.1 You may meet Susan every 3 days and Tim every 5 days in the school. How many days it takes to you when you will meet at least one of them?

Please submit your homework to R421, EE-II