

Homework #4

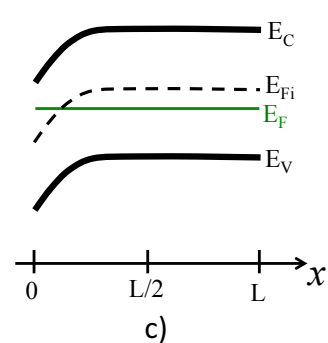
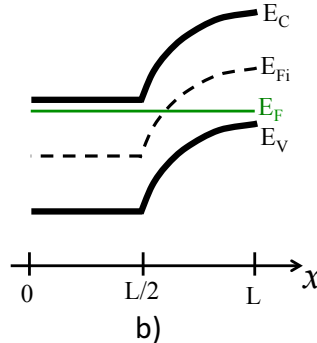
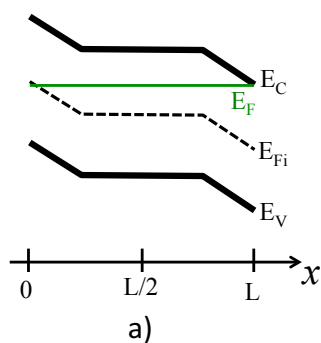
Carrier Transport and pn Junctions – **100 points**

DUE @ Beginning of Class: Tuesday, October 3

1) Answer the following questions, for each of the band diagrams given below (a-c):

(24 points)

- i) Do equilibrium conditions prevail? How do you know?
- ii) Sketch the electrostatic potential (ϕ) inside the semiconductor as a function of x .
- iii) Sketch the electric field (E) inside the semiconductor as a function of x .
- iv) Roughly sketch n and p versus x .
- v) Roughly sketch the electron drift-current density and the electron diffusion-current density as a function of x , on the same plot. Be sure to graph the proper polarity of the current densities and clearly identify the two current components. Give a brief explanation for how you arrived at your sketch.



2) E-Book, problem 5.5 **(4 points)**

3) E-Book, problem 5.9 **(9 points)**

4) E-Book, problem 5.23 **(16 points)**

5) E-Book, problem 5.31 **(6 points)**

6) E-Book, problem 5.36 **(6 points)**

7) E-Book, problem 7.2 **(9 points)**

8) E-Book, problem 7.6 **(10 points)**

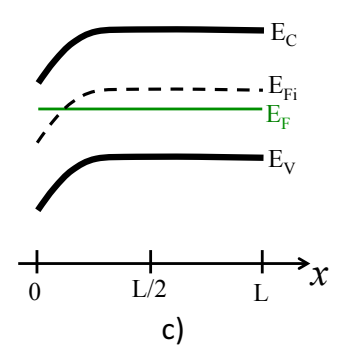
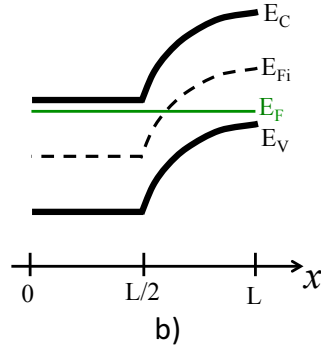
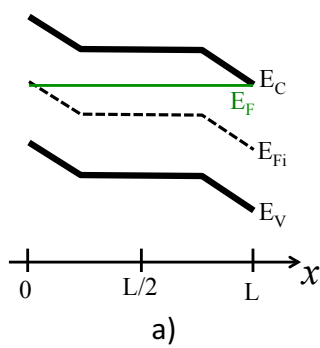
9) E-Book, problem 7.29, assume $V_R \gg V_{bi}$ **(12 points)**

10) E-Book, problem 7.36 – asking to find N_a **(4 points)**

1) Answer the following questions, for each of the band diagrams given below (a-c):

(24 points)

- Do equilibrium conditions prevail? How do you know?
- Sketch the electrostatic potential (ϕ) inside the semiconductor as a function of x .
- Sketch the electric field (E) inside the semiconductor as a function of x .
- Roughly sketch n and p versus x .
- Roughly sketch the electron drift-current density and the electron diffusion-current density as a function of x , on the same plot. Be sure to graph the proper polarity of the current densities and clearly identify the two current components. Give a brief explanation for how you arrived at your sketch.



2) E-Book, problem 5.5 (4 points)

5.5 A silicon sample is 2.5 cm long and has a cross-sectional area of 0.1 cm². The silicon is n type with a donor impurity concentration of $N_d = 2 \times 10^{15} \text{ cm}^{-3}$. The resistance of the sample is measured and found to be 70 Ω . What is the electron mobility?

3) E-Book, problem 5.9 (9 points)

- 5.9** (a) A GaAs semiconductor resistor is doped with donor impurities at a concentration of $N_d = 2 \times 10^{15} \text{ cm}^{-3}$ and has a cross-sectional area of $5 \times 10^{-5} \text{ cm}^2$. A current of $I = 25 \text{ mA}$ is induced in the resistor with an applied bias of 5 V. Determine the length of the resistor. (b) Using the results of part (a), calculate the drift velocity of the electrons. (c) If the bias applied to the resistor in part (a) increases to 20 V, determine the resulting current if the electrons are traveling at their saturation velocity of $5 \times 10^6 \text{ cm/s}$.

4) E-Book, problem 5.23 (16 points)

5.23 Consider three samples of silicon at $T = 300$ K. The n-type sample is doped with arsenic atoms to a concentration of $N_d = 5 \times 10^{16} \text{ cm}^{-3}$. The p-type sample is doped with boron atoms to a concentration of $N_a = 2 \times 10^{16} \text{ cm}^{-3}$. The compensated sample is doped with both the donors and acceptors described in the n-type and p-type samples. (a) Find the equilibrium electron and hole concentrations in each sample, (b) determine the majority carrier mobility in each sample, (c) calculate the conductivity of each sample, (d) and determine the electric field required in each sample to induce a drift current density of $J = 120 \text{ A/cm}^2$.

5) E-Book, problem 5.31 (6 points)

- 5.31** The electron diffusion current density in a semiconductor is a constant and is given by $J_n = -2 \text{ A/cm}^2$. The electron concentration at $x = 0$ is $n(0) = 10^{15} \text{ cm}^{-3}$. (a) Calculate the electron concentration at $x = 20 \text{ }\mu\text{m}$ if the material is silicon with $D_n = 30 \text{ cm}^2/\text{s}$. (b) Repeat part (a) if the material is GaAs with $D_n = 230 \text{ cm}^2/\text{s}$.

6) E-Book, problem 5.36 (6 points)

5.36 The total current in a semiconductor is constant and equal to $J = -10 \text{ A/cm}^2$. The total current is composed of a hole drift current and electron diffusion current. Assume that the hole concentration is a constant and equal to 10^{16} cm^{-3} and assume that the electron concentration is given by $n(x) = 2 \times 10^{15} e^{-x/L} \text{ cm}^{-3}$ where $L = 15 \text{ } \mu\text{m}$. The electron diffusion coefficient is $D_n = 27 \text{ cm}^2/\text{s}$ and the hole mobility is $\mu_p = 420 \text{ cm}^2/\text{V}\cdot\text{s}$. Calculate (a) the electron diffusion current density for $x > 0$, (b) the hole drift current density for $x > 0$, and (c) the required electric field for $x > 0$.

7) E-Book, problem 7.2 (9 points)

7.2 Calculate the built-in potential barrier, V_{bi} , for Si, Ge, and GaAs pn junctions if they each have the following dopant concentrations at $T = 300$ K:

(a) $N_d = 10^{14} \text{ cm}^{-3}$ $N_a = 10^{17} \text{ cm}^{-3}$

(b) $N_d = 5 \times 10^{16}$ $N_a = 5 \times 10^{16}$

(c) $N_d = 10^{17}$ $N_a = 10^{17}$

8) E-Book, problem 7.6 (10 points)

- 7.6** A silicon pn junction in thermal equilibrium at $T = 300$ K is doped such that $E_F - E_{Fi} = 0.365$ eV in the n region and $E_{Fi} - E_F = 0.330$ eV in the p region. (a) Sketch the energy-band diagram for the pn junction. (b) Find the impurity doping concentration in each region. (c) Determine V_{bi} .

9) E-Book, problem 7.29, assume $V_R \gg V_{bi}$ (12 points)

7.29 Consider a silicon pn junction with the doping profile shown in Figure P7.29.

$T = 300$ K. (a) Calculate the applied reverse-biased voltage required so that the space charge region extends entirely through the p region. (b) Determine the space charge width into the n^+ region with the reverse-biased voltage calculated in part (a). (c) Calculate the peak electric field for this applied voltage.

10) E-Book, problem 7.36 – asking to find N_a (4 points)

7.36 Design an abrupt silicon n^+p junction diode that has a reverse breakdown voltage of 80 V.