

EE2800 Assignment 3

Due: 9:00 AM, Mar. 26, 2024

1. Consider a piece of semiconductor, where the electric field and carrier concentration distributions are shown in Fig. 1. (16 marks)
 - a. Sketch the drift directions of electrons and holes, respectively. (4 marks)
 - b. Sketch the drift **current** directions of electrons and holes, respectively. (4 marks)
 - c. Sketch the diffusion directions of electrons and holes, respectively. (4 marks)
 - d. Sketch the diffusion **current** directions of electrons and holes, respectively. (4 marks)

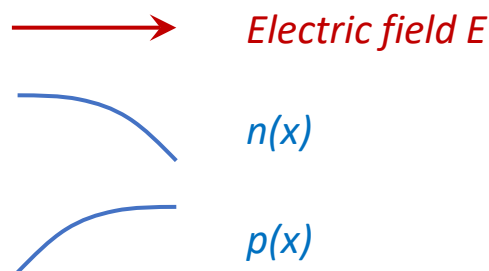


Figure 1. Electric field, electron and hole concentration in a semiconductor.

2. Consider a Si p-n junction at room temperature (300 K). Before contact, the bandgap is 1.12 eV, the Fermi level on the p side is 1.02 eV below conduction band edge and the Fermi level on the n side is 0.88 eV above valence band edge. (16 marks)
 - a. Sketch the energy band diagrams of the p and n regions, respectively, **before** contact? (6 marks)
 - b. If the two regions are brought into contact to form a p-n junction, at thermal equilibrium, sketch the energy band diagram of the full junction. (6 marks)
 - c. What is the contact potential of this p-n junction? (4 marks)

Note: in your sketch you should clearly label the conduction and valence bands, as well as relevant distances between Fermi levels and the band edges.

3. Consider an abrupt Si p-n junction at 300 K, with $N_A = 10^{18} \text{ cm}^{-3}$ on one side and $N_D = 5 \times 10^{15} \text{ cm}^{-3}$ on the other side, assume all dopants are fully ionized, the intrinsic carrier concentration is $n_i = 1.5 \times 10^{10} \text{ cm}^{-3}$, and relative dielectric constant $\epsilon_r = 11.8$. (26 marks)
 - a. Calculate the width of the space charge region W . (5 marks)
 - b. Calculate the penetration into n and p regions, i.e. x_{n0} and x_{p0} , respectively. Is the space charge region width dominated by the p side or the n side? (5 marks)

- c. Calculate the total space charge per unit area in the n region, Q_+/A . (5 marks)
- d. Calculate the maximum electric field E_0 . (5 marks)
- e. Sketch $E(x)$ and charge density as functions of x . (6 marks)

Note: Please label clearly important coordinates of your sketch.

4. Consider an abrupt Si p-n junction at 300 K with an area of 10^{-4} cm^2 , doped with $N_A = 10^{17} \text{ cm}^{-3}$ on one side and $N_D = 10^{15} \text{ cm}^{-3}$ on the other side, assume all dopants are fully ionized, the intrinsic carrier concentration is $n_i = 1.5 \times 10^{10} \text{ cm}^{-3}$, and relative dielectric constant $\epsilon_r = 11.8$. The mobilities and diffusion lengths of electrons and holes at 300 K are given in the below table: (42 marks)

	Mobility	Diffusion length
Electron	$1450 \text{ cm}^2/(\text{V}\cdot\text{s})$	$1.35 \times 10^{-3} \text{ cm}$
Hole	$500 \text{ cm}^2/(\text{V}\cdot\text{s})$	$1.08 \times 10^{-2} \text{ cm}$

- a. Calculate the electron and hole diffusivities, D_n and D_p , respectively. (4 marks)
- b. Calculate the reverse bias current I_0 , then write down the expression of diode current I vs. bias voltage V . In your expression, all numbers should be plugged in with units. (6 marks)
- c. At a forward bias voltage of $V_f = 0.5 \text{ V}$, sketch the energy band diagram of the p-n junction, including the conduction and valence bands and the quasi-Fermi levels (in a similar way as in Lecture 8, slide 16), with labels of critical energy differences (e.g. between quasi-Fermi level and conduction band). (6 marks)
- d. Sketch the electron current I_n , hole current I_p , and total current I , as functions of x at $V_f = 0.5 \text{ V}$, in a similar way as in Lecture 8, slide 17, with labels of current values at critical locations. (6 marks)
- e. Sketch the **minority** carrier concentrations as functions of x in the p and n regions, respectively, at $V_f = 0.5 \text{ V}$, in a similar way as in Lecture 8, slide 19, with labels of carrier concentrations at the edges of space charge region and the equilibrium values. The carrier concentrations within the space charge region do not need to be sketched. (6 marks)
- f. At a reverse bias voltage of $V_r = 0.5 \text{ V}$, calculate the diode current I . (3 marks)
- g. Sketch the energy band diagram of the p-n junction at reverse bias $V_r = 0.5 \text{ V}$ in a similar way as in part c). (6 marks)
- h. Calculate the depletion-layer capacitance at a reverse bias voltage of $V_r = 4 \text{ V}$. (5 marks)