Solid State Devices I - Purdue ECE-606

Homework No. 6

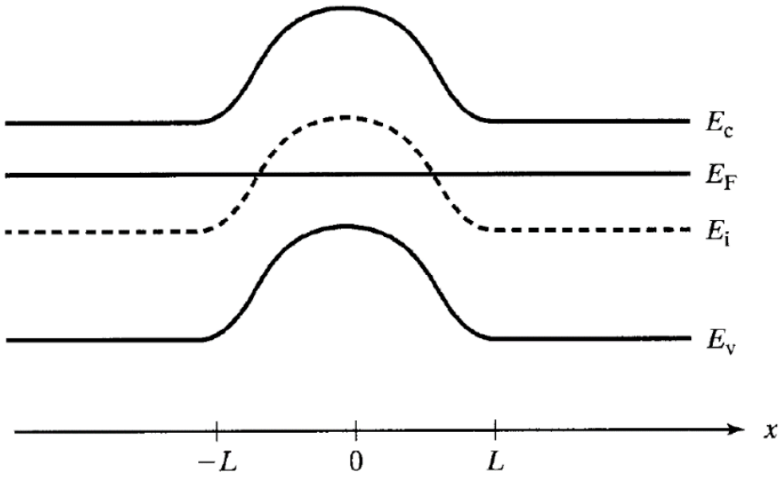
Student name: _____

Student ID: _____

I solved the homework assignment myself without copying a solution from someone else or from the web. Student Initials here: _____

Problem 1. (22 Points total)

The energy band diagram pictured below characterizes a Si sample maintained at room temperature. Note that $E_F - E_i = E_G/4$ at $x = \pm L$ and $E_i - E_F = E_G/4$ at $x = 0$.



a) The semiconductor is in equilibrium. How does one deduce this fact from the given energy band diagram?

b) What is the electron current density (J_N) and hole current density (J_P) at $x = \pm L/2$?

c) Roughly sketch n and p versus x inside the sample.

d) Is there an electron diffusion current at $x = \pm L/2$? If there is a diffusion current at a given point, indicate the direction of current flow.

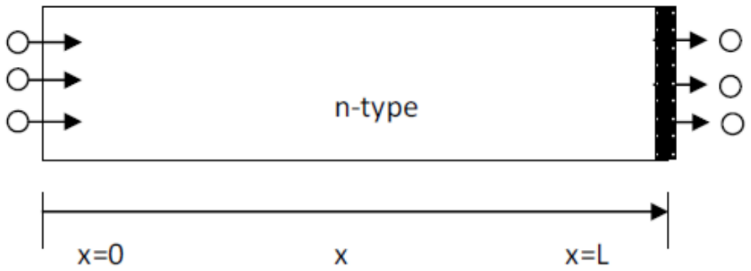
e) Sketch the electric field ($\mathcal{E}$) inside the semiconductor as a function of x.

f) Is there an electron drift current at $x = \pm L/2$? If there is a drift current at a given point, indicate the direction of current flow.

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Problem 2. (20 points total)

Holes are injected and extracted in to an n-doped semiconductor at x=0 as shown in the figure below. However, the doping is not perfectly uniform such that there is a small, constant internal electric field E. Assume that the semiconductor is maintained in the dark and with low level recombination and the right end is contacted with a metal.



a) Obtain an expression for the excess hole density in terms of $\Delta p(x=0)$ and at steady state condition (8 points)

b) Assuming that the minority carrier lifetime is 100ns and the hole mobility is 400cm2/Vs, compute the drift and diffusion current. You can assume that L=10mm, $\Delta p(x=0)=1\times10^{15}/cm^3$ and E=10V/cm at x=0. (8 points)

c) Repeat part a) but now assume that due to contact degradation, the right end has surface recombination velocity S_p. (4 points)

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Problem 3 - (12 points total)

A semi-infinite n-type semiconductor bar is subject to uniform penetrating illumination resulting in a generation rate of G electron-hole pairs per second per cm^2 throughout the bar. G is such that the sample remains in low-level injection. Minority carriers are extracted at the surface at x=0. Obtain an expression for the maximum hole current that can be drawn from the bar in steady-state.

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Problem 4 - (9 points total)

Sketch the energy band diagram for an ideal p^+-n step junction diode showing the carrier activity in and near the depletion region when

(a) $V_A=0$.

(b) $V_A>0$.

(c) $V_A<0$.

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Problem 5 - (25 points total)

Solve this problem with pn-junction lab on nanoHUB. Either with:
https://nanohub.org/tools/pntoy or https://nanohub.org/tools/abacus

a)

- Configure the tool to consider a symmetric pn-diode with 1e15/cm^3 p and n doping and identical lengths of 3μm (micrometers).
- In the "Environment" tab increase the applied voltage to 0.8 and increase the number of bias points to 25
- Leave the rest of the parameters at the default level and run the simulation.
- Plot/Download the image of the "Doping, Electron, and Hole Density at Equilibrium"
- Plot/Download the image of the "Net Charge Density (at equilibrium)"
- Plot/Download the image of the "Electric Field (at equilibrium)"

Interpret the three plots and comment on the validity of the depletion region approximation. [2 points]

b)

- Start from simulations in a) and 2 run two more simulations.
  Increase the doping on the p and n side to 1e16/cm3. Run the simulation
  Increase the doping on the p and n side to 1e17/cm3. Run the simulation.
- Plot/Download the image of the "Electric Field (at equilibrium)" Click the "All" button to compare the three simulation.
- Plot/Download the image of the "Energy Band Diagram (at equilibrium)" Click the "All" button to compare the three simulations
- Plot/Download the image of the "I-V Characteristics" Click the "All" button to compare the three simulations
- Zoom into the "I-V Characteristics" for [0.5V,0.8V] and [0,100A/cm^2]. Click the "All" button to compare the three simulations.

Interpret the results of the simulation in the three different simulations in the 4 different plots. Relate the impact of the various physical quantities to each other. [6 points]

c) Use the results from a) and b).

- Select the "Energy Band Diagram (at applied bias)" for the low 1e15/cm^3 doping simulation.
- Scan through the biases and watch the evolution of the band edge.

- Plot/Download the image of the "Energy Band Diagram (at applied bias)" at a bias of 0.4V
- Plot/Download the image of the "Energy Band Diagram (at applied bias)" at a bias of 0.8V

Interpret the plots in light of the "I-V Characteristic". Why is there an asymmetry in the p and n side? [6 points]

d) Use the results from a), b), repeat the exercise of c) but view the high doping 1e17/cm^3 doping results. Compare and contrast the results of d) with c). [6 points]

e)

- Clear all the results. Now enter a more modern, very high doping concentration on the p and n side of 5e18/cm^3. Run the simulation.
- Now reduce the number of "nodes" in the p-type and the n-type structure to 20. Run the simulation.
- Plot/Download the image of the "Doping, Electron, and Hole Density at Equilibrium" Click the "All" button to compare the two simulations
- Plot/Download the image of the "Electric Field (at equilibrium)" Click the "All" button to compare the two simulations
- Plot/Download the image of the "Energy Band Diagram (at equilibrium)" Click the "All" button to compare the two simulations
- Plot/Download the image of the "I-V Characteristics" Click the "All" button to compare the two simulations

Compare, contrast, and interpret the two simulation results. [5 points]

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Problem 6 - (12 points total)

Sketch and compare the plots of forward current-voltage characteristics of Ge, Si, and GaAs p^+-n junction diode. Assume that the diodes have identical structures and doping concentration. Please give a short mathematical argument to support your I–V sketch.

You will not secure any credit for drawing the characteristics without a proof/reasoning.