

EE 557 - Semiconductor Devices I

Responsible: Prof. Elisa Matioli

Mid-term Exam

November 11th, 2024

YOUR NAME _____

General Instructions:

1. The exam consists of 3 problems. Use additional sheets to show your work and the answer to the questions, but be sure to put your name on the first page.
2. All sketches must be adequately labeled.
3. If you use the attached plots to solve a problem, please indicate your choice of values on the solution of the exercise.
4. All needed values to solve the exercises are either given or determined from previous exercises in this exam. At the end of the exam, there are three pages with useful material parameters.
5. You will be graded on both your solution (that is, the work shown) and your final answer. It is possible to get the right answer, but not receive full credit if your reasoning is unclear. A few words of explanation are required.
6. Indicate units on all numerical answers. Values without units are not correct answers.

Grades:

Problem 1 (2 points):

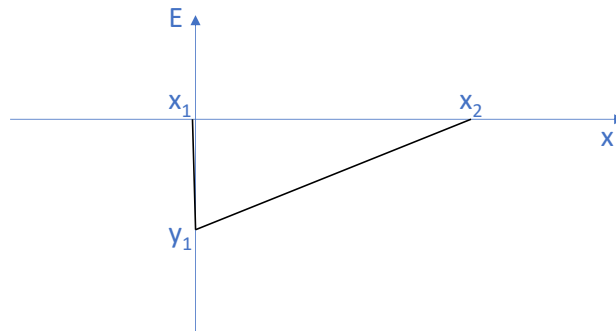
Problem 2 (5 points):

Problem 3 (7 points):

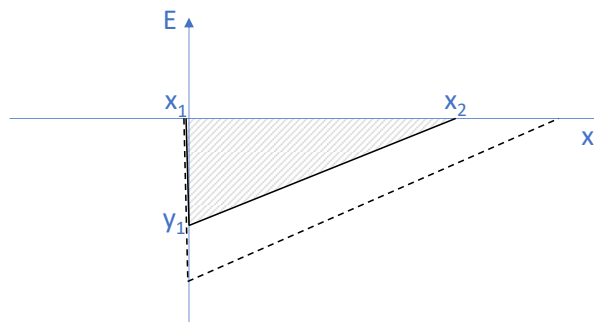
Total grade:

Problem 1 (2 points): What is the position of the Fermi level with respect to the valence band ($E_F - E_V$) for a silicon sample at 300 K doped with n_i (with fully ionized donors)? Justify your answer.

Problem 2 (5 points): You would like to make a pn diode with the corresponding electric field profile under thermal equilibrium at room temperature ($|x_1| \ll |x_2|$), based on Silicon (with uniformly doped in p and n sides). The majority carrier mobility at each side should be $400 \text{ cm}^2/\text{V}\cdot\text{s}$ and $200 \text{ cm}^2/\text{V}\cdot\text{s}$ respectively.

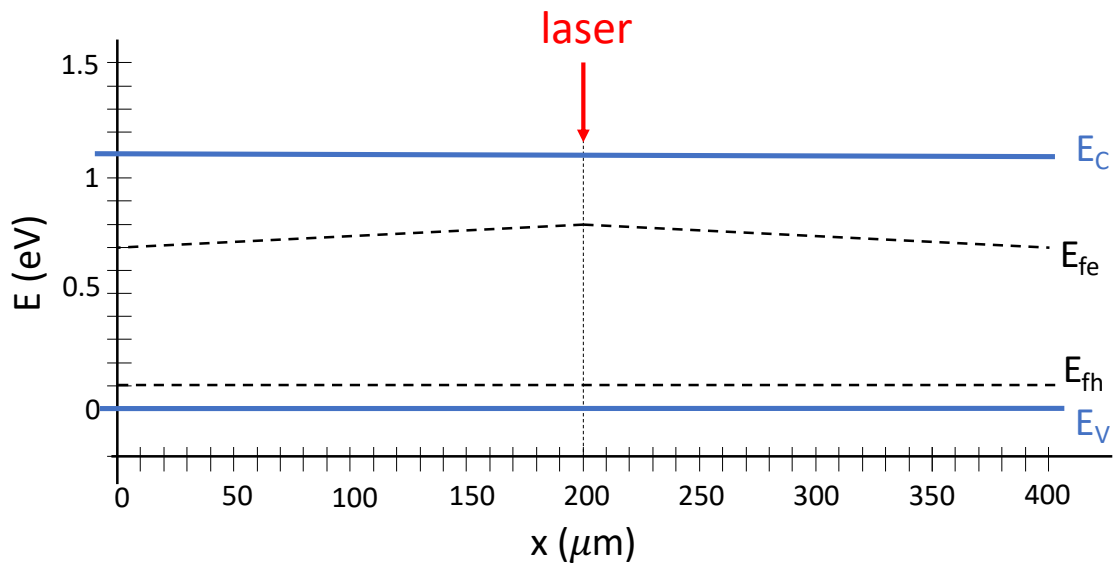


- Which side is n-type and which side is p-type? What is the donor concentration at *n* side and the acceptor concentration at *p* side? Explain the reason in one or two sentences. **(1 point)**
- Determine the values of x_1 , x_2 , and y_1 (with units). **(1 point)**
- What is the physical meaning of the shaded area of the triangle $x_1x_2y_1$ (which physical parameter of the pn junction it corresponds to)? If the electric field profile changed from the solid line to the dashed line as indicated below, what would be the reason for such a change? Calculate the maximum area under the triangle that could be achieved. **(2 points)**



- Draw the band diagram of this junction under $+0.6 \text{ V}$. For this, first calculate the distance of the Fermi level to the bands in quasi neutral region on each side, and then draw the band diagram in scale. **(1 point)**

Problem 3 (7 points): Consider a 400 μm -long Silicon bar at room temperature in steady state.



- a. Circle the terms that apply to the situation (**1 point if all are correct**):
- thermal equilibrium / out of equilibrium
 - uniformly doped / non-uniformly doped
 - n-type / p-type
 - Is there an electric field: Yes / No
 - Is there electron current: Yes / No
- b. Estimate the doping concentration and the minority carrier concentration in equilibrium n_0 and the excess minority carriers (n') injected by the laser. Is this low-level or high-level injection? (**1 point**)
- c. Determine the minority carrier diffusion coefficient and lifetime (use plot 2) (**1 point**)
- d. Plot the minority carrier concentration versus x , in scale across the entire bar. Write the equation, and the important constants that describes this process. Describe what is physically happening in this situation (**2 point**).
- e. What is the current density of minority carriers generated at the laser point? Which direction is it flowing? (**1 point**)
- f. When the laser is turned-off, explain what happens to the minority carriers and the quasi-fermi levels, and final band structure. Give the expression of the excess carriers versus time at the laser point, after it is shut off. (**1 point**)

Extra Information:

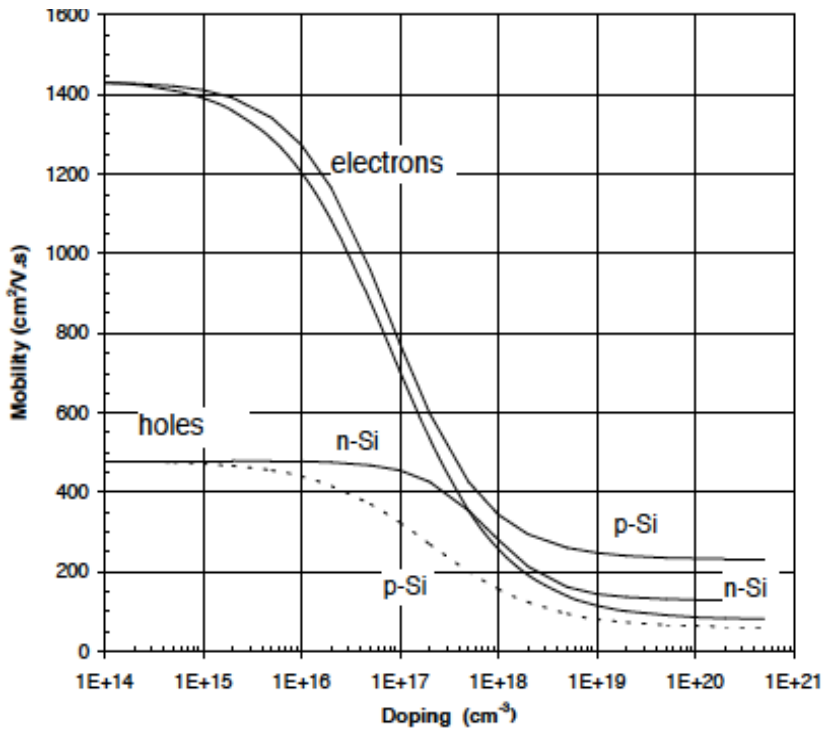
Physics constants:

- $q = 1.6 \times 10^{-19} \text{ C}$
- $\epsilon_0 = 8.85 \times 10^{-14} \text{ F/cm}$
- $k = 1.38 \times 10^{-23} \text{ J/K}$
- $m_e = 9.1 \times 10^{-31} \text{ kg}$
- $n_i \text{ (at 300K)} = 10^{10} \text{ cm}^{-3}$

Si constants:

- $m_e^* = 0.26 m_e$
- $m_h^* = 0.36 m_e$
- $E_g = 1.12 \text{ eV @ RT}$
- $v_{sat_n} = 1 \times 10^7 \text{ cm/s}$
- $v_{sat_p} = 0.7 \times 10^7 \text{ cm/s}$
- $k_{rad} = 2 \times 10^{-15} \text{ cm}^3/\text{s}$
- $k_{eeh} = 1.8 \times 10^{-31} \text{ cm}^6/\text{s}$
- $k_{ehh} = 0.95 \times 10^{-31} \text{ cm}^6/\text{s}$
- $c_e = 1 \times 10^{-11} \text{ cm}^3/\text{s}$
- $c_h = c_e;$
- $\epsilon_{Si}^r = 11.7$
- $E_{Si}^{Si \text{ breakdown}} = 300 \text{ kV/cm}$

Plot 1



Plot 2

