Check the official solution for solution.

EE2: Physics for Electrical Engineers
Finals Spring 2016
June 6th 2016, 11:30 am to 2:30 pm, Haines A18

Instructors: Prof. Chee Wei Wong, Jinghui Yang and Yi-Ping Lai
Closed book, but with 3-sheet (6-sides of 8.5" × 11" paper) of notes.
Please use calculator.

Question 1. (16 points) Chapters 1 to 4

1.A. (8 points). With the Schrödinger wave equation, we describe the electron in free space, infinite potential well, step potential function and one-electron (hydrogen) atom to you. How should the time-independent wave function look like in an infinite potential well, for the lowest energy state ($n = 1$) and the first excited state ($n = 2$)? What are the quantized (discretized) energy levels in an infinite potential well? Please write down the solutions of wave functions and energy levels and draw a diagram to illustrate this.

1.B. (8 points). Consider a *p*-doped extrinsic semiconductor in equilibrium. Plot the conventional density of states versus k for both the conduction and valence bands. Superimpose the Fermi-Dirac distribution function on top. For a p-doped semiconductor, the Fermi level E_F is below the intrinsic Fermi level E_{Fi}. Draw the resulting distribution of the electron and hole concentrations (not equal of course!).

Question 2. (15 points) Chapter 5: Carrier Transport Phenomena

The hole concentration in a p-type semiconductor is given by $p(x) = 10^{16}(1 + x/L)^2$ cm^{-3} for $-L \leq x \leq 0$ where $L = 12$ μm. The hole diffusion coefficient is $D_p = 10$ cm^2/s. Calculate the hole diffusion current density at $x = -6$ μm.

Question 3. (16 points) Chapter 6: Nonequilibrium Excess Carriers in Semiconductors

Consider a p-type Si semiconductor at T = 300K doped at $N_a = 5 \times 10^{15}$ cm^{-3}. Determine the position of the Fermi level with respect to the intrinsic Fermi level. Secondly, if excess carriers are generated such that the excess carrier concentration is 10 percent of the thermal-equilibrium majority carrier concentration, determine the quasi-Fermi levels with respect to the intrinsic Fermi level.

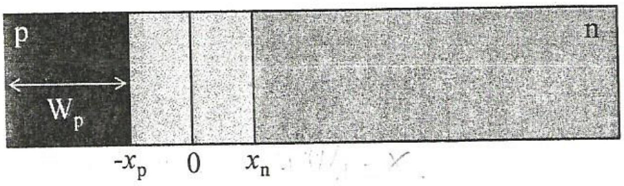
Question 4. (15 points) Chapter 7: The pn Junction

We described junction breakdown in class. Consider a symmetrically doped silicon pn junction diode with doping concentrations of $N_a = N_d = 2 \times 10^{16}$ cm^{-3}. Silicon permittivity ϵ_s is $12.11 \times 8.85 \times 10^{-12}$ F/m. Assuming the critical electric field $E_{crit} = 4 \times 10^5$ V/cm, determine the breakdown voltage.

Question 5. (20 points) Chapter 8: The pn Junction Diode - I

5.A. (10 points) An ideal germanium pn junction diode has the following parameters: $N_a = 4 \times 10^{15}$ cm^{-3}, $N_d = 2 \times 10^{17}$ cm^{-3}, $D_p = 48$ cm^2/s, $D_n = 90$ cm^2/s, $\tau_{po} = \tau_{no} = 2 \times 10^{-6}$ s, and $A = 10^{-4}$ cm^2. Determine the diode current for: **(a)** a forward bias voltage of 0.25 V, and **(b)** a reverse-biased voltage of 0.25V.

5.B. (10 points) Consider a short pn diode, with short p side as below. Describe how the minority carrier electron changes with distance on the short p side. What is the expression for the minority carrier electron current density?



Question 6. (18 points) Chapter 8: The pn Junction Diode - II

6.A. (8 points). In class, we taught the deviations from an ideal pn diode. In forward bias, the presence of traps (imperfections) in a semiconductor resulted in Shockley-Reed-Hall recombination. In forward bias and under high level injection, the I-V curve also deviates from an ideal I-V curve. Please draw the resulting I-V curve with both effects, under forward bias.

6.B. (10 points) Consider a silicon pn junction diode with doping concentrations of $N_a = N_d = 4 \times 10^{16}$ cm^{-3} and a cross-sectional area A of 10^{-4} cm^2. Assume minority carrier lifetimes of $\tau_o = \tau_{po} = \tau_{no} = 10^{-7}$ s. Calculate the forward bias voltage at which the ideal diffusion current is equal to the recombination current at T = 300K.

Helpful constants:
Boltzmann's constant $k = 1.38 \times 10^{-23}$ J/K
Planck's constant $h = 6.625 \times 10^{-34}$ J-s
Electronic charge $e = 1.60 \times 10^{-19}$ C
Silicon at 300K $n_i = 1.5 \times 10^{10}$ cm^{-3}