UNIVERSITY OF CALIFORNIA, SANTA BARBARA

Department of Electrical and Computer Engineering

ECE 122A VLSI Principles

Homework #3 **Semiconductor Physics, IC Fabrication, P/N Junctions and MOSCAP**

Due Date: **10/27/2023, Friday, 5:00 PM**

Problem 1 Energy bands and ionization energy (20)

(A) Derive the expression for the allowed electron energies in an atom (Slide 5, Lecture 4). (5)

(B) Using the hydrogen model and using the expression derived in (A) estimate the typical ionization energy of a donor atom in Si. Hint: Assume the relative permittivity of Si to be 12 and use the effective mass of electrons. (10)

(B) If Si is used as a dopant in GaAs, will it be a donor or acceptor? Explain your answer. (5)

Problem 2 Carrier Statistics (20)

(A) Show that the values of the Fermi-Dirac distribution function, at a pair of energies symmetric about the Fermi energy E_f, are complementary, i.e., show that $f\left(E_f - \Delta E\right) + f\left(E_f + \Delta E\right) = 1$, independent of temperature. (5')

(B) An N-type sample of silicon has uniform density (N_d = 10^{16}/cm^{-3}) of arsenic, and a P-type silicon sample has a uniform density (N_a = 10^{17}/cm^{-3}) of boron. For each sample, determine the following. (15')

(i) The temperature at which the intrinsic concentration n_i exceeds the impurity density by factor of 10.

(ii) The equilibrium minority-carrier concentrations at 300 K. Assume full ionization of impurities.

(iii) The Fermi level relative to the valence-band edge (E_V) and conduction band edge (E_C) in each material at 300 K.

(iv) The electron and hole concentrations and the Fermi level if both types of impurities are present in the same sample.

Use the following expressions for N_C and N_V:

$$N_C = 2\left[\frac{2\pi m_n kT}{h^2}\right]^{\frac{3}{2}}, N_V = 2\left[\frac{2\pi m_p kT}{h^2}\right]^{\frac{3}{2}}$$

Problem 3 P-N Junction (I)

An abrupt silicon (n_i = 5 x 10^{10} cm^{-3}) p-n junction consists of a p-type region containing 3×10^{16} cm^{-3} acceptors and an n-type region containing 5×10^{17} cm^{-3} donors.

(a) Calculate the built-in potential of this p-n junction. (5')

(b) Calculate the total width of the depletion region if the applied voltage V_a equals 0, 0.5 and -2.5 V. (5')

(c) Calculate maximum electric field in the depletion region at 0, 0.5 and -2.5 V. (5')

(d) Calculate the potential across the depletion region in the n-type semiconductor at 0, 0.5 and -2.5 V. (5')

Problem 4 P-N Junction (II)

(A) Derive the expression for the depletion width (without bias and with an assumed bias of V – Slide 13, Lecture 5). Use the depletion width to estimate the charge in the depletion regions, and hence, derive the capacitance expression (Slide 14, Lecture 5).

(B) We have a symmetric p-n Silicon junction (N_A = N_D = x cm^{-3}). If the peak electric field in the junction at breakdown is 10^6 V/cm, under a reverse breakdown voltage of 15 V, what is x? (10)

Problem 5 MOS Capacitor (I)

A MOSCAP was fabricated on Silicon with a channel doping concentration of N_A. At zero gate-bias the hole concentration at the oxide-semiconductor interface (y=0) and at a depth of y = 20 nm was observed to be n_i (intrinsic carrier concentration) and 10^{16} cm^{-3} respectively. Assuming full depletion, calculate N_A.

Problem 6 MOS Capacitor (II)

Consider an MOS capacitor with the SiO_2 thickness of 50 nm. Assume N_a = 2×10^{18} cm^{-3}, and metal work function to be 4.4 eV.

(A) Draw the band diagram along the MOS structure in depletion, accumulation, and inversion mode. (10')

(B) Sketch to show the accumulated charges at the metal-oxide, and semiconductor-oxide interface in depletion, accumulation, and inversion. Show either in band diagrams or a section crossing metal-oxide-semiconductor. (10')