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OFFICE OF THE DEPUTY PRINCIPAL
ACADEMICS, STUDENT AFFAIRS AND RESEARCH

UNIVERSITY EXAMINATIONS

2021/2022 ACADEMIC YEAR

FOURTH YEAR FIRST SEMESTER REGULAR EXAMINATION

FOR THE DEGREE OF BACHELOR OF EDUCATION SCIENCE

COURSE CODE: PHY 425E

COURSE TITLE: THE PHYSICS OF SEMICONDUCTOR DEVICES

DATE: 1ST FEBRUARY, 2022 TIME: 1400 – 1700 HRS

INSTRUCTION TO CANDIDATES

- SEE INSIDE

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REGULAR – MAIN EXAMINATION

PHY 425E: THE PHYSICS OF SEMICONDUCTOR DEVICES

STREAM: BED (Scie) DURATION: 3 Hours

INSTRUCTIONS TO CANDIDATES

*a) Answer the **TWO** question in **SECTION A** and any other **THREE** questions in **SECTION B.***

b) The following constants maybe useful

Boltzmann's constant	$K = 1.38 \times 10^{-23}$ J/K or 8.62×10^{-5} eV/K
Electronic charge	$e = 1.60 \times 10^{-19} C$
Free electron rest mass	$m_o = 9.11 \times 10^{-31}$ Kg
Permeability of free space	$\mu_o = 4\pi \times 10^{-7}$ H/m
Permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12}$ F/m or 8.85×10^{-14} F/cm
Dielectric constant of silicon	$\epsilon = 11.7$
Planck's constant	$h = 6.625 \times 10^{-34} J/s$
	$\hbar = \frac{h}{2\pi} = 1.054 \times 10^{-34}$ J/s
Proton rest mass	$M = 1.67 \times 10^{-27}$ Kg

SECTION A (28 MARKS)

Question One (14 Marks)

a) Draw the energy level diagram for silicon doped with arsenic atoms at 300 K and 600 K, showing the Fermi level and donor level relative to intrinsic level in each case. (4 Marks)

b) Distinguish between n-type compensated and p-type compensated semiconductor. (2 Marks)

c) Using well labelled diagram, differentiate between degenerately doped n-type semiconductor and degenerately doped p-type semiconductor. (2 Marks)

d) The conductivity of intrinsic Si is 4.17×10^{-5} and 4×10^{-4} $(\Omega - m)^{-1}$ at $0\,^{\circ}C$ and $27\,^{\circ}C$, respectively. Determine the average band gap of Si. (4 Marks)

e) Describe Hall effect? (2 Marks)

Question Two (14 Marks)

a) Differentiate between avalanche breakdown and zener breakdown in reverse biased pn junction? (2 Marks)

b) An abrupt silicon pn junction has dopant concentrations of $N_a = 2\times10^{16} cm^{-3}$ and $N_d = 2\times10^{15} cm^{-3}$ at $T = 300K$. Calculate built-in potential V_{bi} and space charge width (W) at $V_R = 8V$. (4 Marks)

c) Using well labelled I-V characteristic of tunnel diode, describe how a negative differential resistance region is generated. (3 Marks)

d) Distinguish between Schottky junction and Ohmic junction. (2 Marks)

e) Explain the conditions of cutoff, saturation, and inverse-active modes of a bipolar transistor. (3 Marks)

SECTION B (42 MARKS)

Question Three (14 Marks)

a) Given that $n = N_C \exp\left[-\left(\frac{E_C - E_F}{kT}\right)\right]$ and $p = N_v \exp\left[-\left(\frac{E_F - E_v}{kT}\right)\right]$, deduce intrinsic carrier concentration expression, n_i. (4 Marks)

b) Plot graph of lnσ versus $1/T$ for an intrinsic semiconductor. (2 Marks)

c) Silicon at $T = 300$ K is doped with Arsenic atoms such that the concentration of electrons is $n_o = 5\times10^4$ cm^{-3} and intrinsic carrier concentration, $n_i = 1.5\times10^{10} cm^{-3}$. For silicon $\left(N_C = 2.8\times10^{19} cm^{-3} \text{ and } N_V = 1.04\times10^{19} cm^{-3}\right)$

i. Calculate p_o (3 Marks)

ii. Which carrier is the minority carrier? (1 Mark)

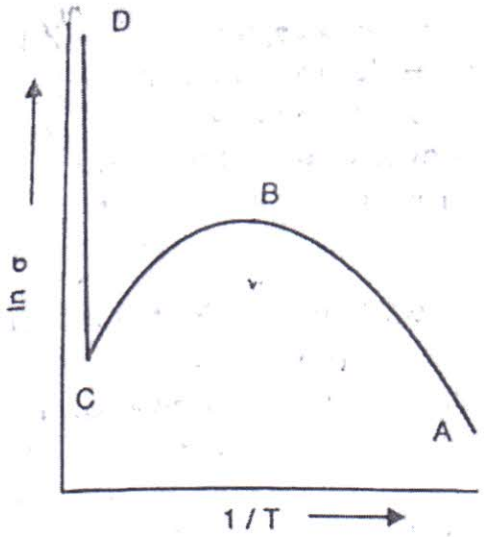
iii. Find $E_C - E_F$ (2 Marks)

iv. Determine $E_F - E_V$ (2 Marks)

Question Four (14 Marks)

a) Sketch a variation of electron concentration, n with temperature showing partial ionization, extrinsic and intrinsic regions in n-type semiconductor. (4 Marks)

b) The temperature dependence of electrical conductivity for a typical n-type semiconductor is shown below. Briefly describe the conclusions that can be drawn from the regions AB, BC and CD. (4 Marks)



c) In intrinsic gas, the electron and hole mobilities are 0.85 and $0.04\ \mathrm{m}^2/V-s$ respectively and the corresponding effective masses are $0.068\,m_o$ and $0.5\,m_o$ respectively where m_o is the rest mass of the electron. Given the energy gap at 300 K as $1.43\,eV$, determine intrinsic carrier concentration and conductivity. (6 Marks)

Question Five (14 Marks)

a) Write the expression of the current density of ideal diode. (2 Marks)

b) State four assumptions considered in derivation of ideal current–voltage relationship of a pn junction. (4 Marks)

c) Consider a gallium arsenide sample at T=300K. A Hall effect device has been fabricated with the following parameters: d=0.001 cm, W=0.05 cm and L=0.5 cm. The electrical parameters are: I= 2.5 mA, $V_X = 2.2$ V and $B_Z = 2.5 \times 10^{-2}$ Tesla. The Hall voltage is $V_H = -4.5mH$. Find

i. the conductivity type, (2 Marks)

ii. the majority carrier concentration (2 Marks)

iii. the mobility (2 Marks)

iv. the resistivity (2 Marks)

Question Six (14 Marks)

a) Describe the charge flow in a forward-biased Schottky barrier diode. (2 Marks)

b) An ideal rectifying contact is formed by depositing gold on n-type silicon doped at $10^{15} cm^{-3}$. Given that the electron affinity χ of Si is 4.01 eV and the work function of gold is 5.1 eV

i. Draw the energy-band diagrams of the two materials before the junction is formed. (2 Marks)

ii. Draw the ideal energy band at zero bias after the junction is formed. (2 Marks)

iii. Calculate the ideal barrier height ϕ_B (2 Marks)

c) Sketch the I-V characteristics of a Schottky junction. (3 Marks)

d) An abrupt Si p-n junction has $N_a = 10^{17} cm^{-3}$ on the p side and $N_d = 10^{16} cm^{-3}$ on the n side. At 300 K, calculate the Fermi levels and draw an equilibrium band diagram. (3 Marks)

Question Seven (14 Marks)

a) State the difference between JFET and MOSFET. (2 Marks)

b) Using well labelled diagrams, explain the working of n-channel JFET. (6 Marks)

c) A uniformly doped silicon pnp transistor is biased in the forward-active mode. The doping concentrations are $N_E = 10^{18}\,cm^{-3}$, $N_B = 5\times10^{16}\,cm^{-3}$, and $N_C = 10^{15}\,cm^{-3}$ ($n_i = 1.5\times10^{10}\,cm^{-3}$). Calculate the values of

i. thermal-equilibrium minority carrier electron concentration in the emitter n_{E0}, (2 Marks)

ii. thermal-equilibrium minority electron concentration in the base, p_{B0} and (2 Marks)

iii. thermal-equilibrium minority carrier hole concentration in the collector n_{CO} (2 Marks)

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