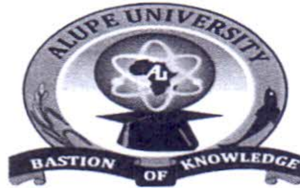

ALUPE UNIVERSITY

OFFICE OF THE DEPUTY VICE CHANCELLOR

ACADEMICS, RESEARCH AND STUDENTS AFFAIRS

UNIVERSITY EXAMINATIONS

2024/2025 ACADEMIC YEAR

FOURTH YEAR FIRST SEMESTER REGULAR MAIN EXAMINATION

FOR THE DEGREE OF BACHELOR OF EDUCATION SCIENCE

COURSE CODE: **PHY 425E**

COURSE TITLE: **THE PHYSICS OF SEMICONDUCTOR DEVICES**

DATE: **9th January 2025** **TIME: 1400 – 1700**

INSTRUCTION TO CANDIDATES

- **SEE INSIDE**

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MAIN EXAMINATION

PHY 425E: THE PHYSICS OF SEMICONDUCTOR DEVICES

STREAM: BED (SCIENCE) **DURATION: 3 Hours**

INSTRUCTIONS TO CANDIDATES

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

b) *The following constants maybe useful*

Boltzmann's constant	$k = 1.38\times10^{-23}$ J/K or 8.62×10^{-5} eV/K
Electronic charge	$e = 1.60\times10^{-19} C$
Free electron rest mass	$m_o = 9.11\times10^{-31}$ Kg
Permeability of free space	$\mu_o = 4\pi\times10^{-7}$ H/m
Permittivity of free space	$\epsilon_0 = 8.85\times10^{-12}$ F/m or 8.85×10^{-14} F/cm
Dielectric constant of silicon	$\epsilon = 11.7$
Planck's constant	$h = 6.625\times10^{-34} J/s$ or $\hbar = \frac{h}{2\pi} = 1.054\times10^{-34}$ J/s
Proton rest mass	$M = 1.67\times10^{-27}$ Kg
Density of states in silicon (T=300K),	$(N_C = 2.8\times10^{19} cm^{-3})$
Density of states in silicon (T=300K)	$(N_V = 1.04\times10^{19} cm^{-3})$
n_i, *Silicon (300 K)*	$n_i = 1.5\times10^{10} cm^{-3}$
n_i, *GaAs (300 K)*	$n_i = 1.8\times10^{6} cm^{-3}$
n_i, *GaAs (400 K)*	$n_i = 3.28\times10^{9} cm^{-3}$

SECTION A (28 MARKS)

Question One (14 Marks)

a) Briefly describe the effect of adding acceptor impurity atoms in a semiconductor. (3 Marks)

b) What is the meaning the following terms applicable to semiconductor physics course

i) Acceptor level (1 Mark)

ii) Donor level (1 Mark)

iii) Mobility of the charge carrier (1 Mark)

iv) Drift velocity (1 Mark)

c) Draw a well labelled energy level diagram of p-type semiconductor and explain what happens to the charge carriers when T > 0. (4 Marks)

d) A particular intrinsic semiconductor has resistivity of $50\,\Omega - cm$ at $T = 300\,K$ and $5\,\Omega - cm$ at $T = 330\,K$. Determine the bandgap energy of the semiconductor in eV given that $\frac{E_g}{2k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) = \ln\frac{\sigma_2}{\sigma_1} + \frac{3}{2}\ln\frac{T_1}{T_2}$. (3 Marks)

Question Two (14 Marks)

a) Draw a well labelled energy band diagram of reverse biased pn junction. (2 Marks)

b) Sketch a well labelled energy-band diagram of the npn bipolar transistor under zero bias and under a forward-active mode bias. (4 Marks)

c) Using band structure plot of GaAs, describe negative differential mobility in Gunn diode. (3 Marks)

d) State any three advantages of light emitting diode. (3 Marks)

e) Differentiate between Schottky junction and Ohmic junction (2 Marks)

SECTION B (42 MARKS)

Question Three (14 Marks)

a) With help of a well labelled diagram, distinguish between direct and indirect bandgap semiconductor. (4 Marks)

b) 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 the expression of intrinsic carrier concentration, n_i. (4 Marks)

c) Consider GaAs at $T = 300\,K$.

i) Determine p, if $E_i - E_F = 0.35\,eV$ (2 Marks)

ii) Assuming that p from part (i) remains constant, determine value of $E_i - E_F$, when $T = 400\,K$. (2 Marks)

iii) Find value of n in both parts i) and part ii) (2 Marks)

Question Four (14 Marks)

a) The conductivity versus temperature for typical n-type semiconductor is shown in Figure 1.

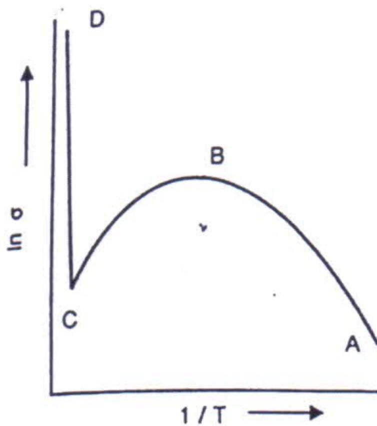

Figure 1

Briefly describe what happens in the following regions

i) AB (2 Marks)

ii) BC (2 Marks)

iii) CD (1 Mark)

b) Consider a germanium semiconductor at $T = 300\,K$. Calculate the thermal equilibrium concentrations of n and p for $N_d = 5\times10^{15}\,cm^{-3}$ and $N_a = 0$ (6 Marks)

c) What is the difference between n-type compensated semiconductor, p-type compensated semiconductor and completely compensated semiconductor. (3 Marks)

Question Five (14 Marks)

a) The Hall effect apparatus are illustrated in Figure 2.

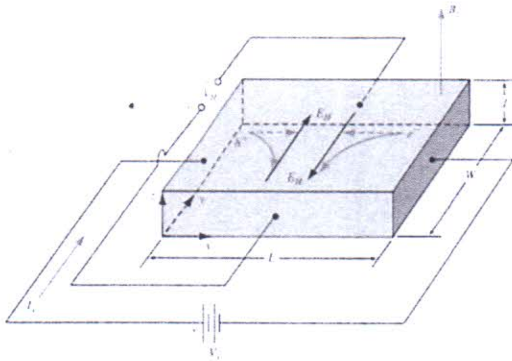

Figure 2

In steady state, $qE_y = qv_x B_z$. Deduce expressions of the following for n-type semiconductor.

i) Hall voltage, V_H (4 Marks)

ii) The hole concentration, n (1 Mark)

iii) The hole mobility, μ_n (3 Marks)

b) Consider silicon at $T = 300\,K$. A Hall effect device is fabricated with the following geometry: $d = 0.005\,cm$, $W = 0.05cm$, and $L = 0.5cm$. The electrical parameters are:

$I_x = 0.5mA$, $V_x = 1.25V$, and $B_z = 6.5 \times 10^{-2} Tesla$. The Hall field is $E_H = -16.5 mV/cm$.

Determine:

i) the Hall voltage, (2 Marks)

ii) the majority carrier concentration and (2 Marks)

iii) the majority carrier mobility (2 Marks)

Question Six (14 Marks)

a) State any four assumptions in deriving the ideal diode equation. (4 Marks)

b) A silicon pn junction at $T = 300K$ with zero applied bias has doping concentrations of $N_d = 5 \times 10^{16} cm^{-3}$ and $N_a = 5 \times 10^{15} cm^{-3}$. Given that

$$x_n = \left\{ \frac{2 \in_s V_{bi}}{e} \left[\frac{N_a}{N_d}\right]\left[\frac{1}{N_a + N_d}\right] \right\}^{1/2} \text{ and } W = \left\{ \frac{2 \in_s V_{bi}}{e} \left[\frac{N_a + N_d}{N_a N_d}\right] \right\}^{1/2}.$$

Determine

i) V_{bi} (2 Marks)

ii) x_n (2 Marks)

iii) W (2 Marks)

iv) x_p (2 Marks)

c) Using a well labelled energy-band diagram, show a pn junction in thermal equilibrium, when both the n and p regions are degenerately doped. (2 Marks)

Question Seven (14 Marks)

a) Highlight the four operating modes of transistors. (4 Marks)

b) With the help of a well labelled diagram, explain the working mechanism of n-channel D-MOSFET in depletion mode. (4 Marks)

c) A silicon npn bipolar transistor is uniformly doped and biased in the forward-active region. The neutral base width is $x_B = 0.8\mu m$. The transistor doping concentrations in the emitter, base and collector are $N_E = 5\times10^{17}\,cm^{-3}$, $N_B = 10^{16}\,cm^{3}$ and $N_C = 10^{15}\,cm^{-3}$, respectively. Use ($n_i = 1.5\times10^{10}\,cm^{-3}$). Calculate thermal-equilibrium minority carrier hole, electron and hole concentrations in the emitter, base and collector (p_{E0}, n_{B0} and p_{CO}) (6 Marks)

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