UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2022/2023

COURSE NAME	:	FUNDAMENTAL OF SEMICONDUCTOR
COURSE CODE	:	BEJ 33103
PROGRAMME CODE	:	BEJ
EXAMINATION DATE	:	FEBRUARY 2023
DURATION	:	3 HOURS
INSTRUCTION		1. ANSWER ALL QUESTIONS 2.THIS FINAL EXAMINATION IS CONDUCTED VIA **CLOSED BOOK.** 3.STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

THIS QUESTION PAPER CONSISTS OF **SEVEN (7)** PAGES

Q1 (a) List **ONE (1)** elemental semiconductor materials and **ONE (1)** compound semiconductor materials.

(1 mark)

(b) Sketch the schematic energy band diagrams corresponding to conductor, semiconductor and insulator.

(3 marks)

(c) Explain the electrical conductivities of the materials based on the illustrated diagram in part **Q1(b)**.

(6 marks)

(d) A Gallium Arsenide (GaAs) sample is doped with 8.65×10^{15} boron per cm^3.

(i) Calculate the carrier concentrations and the Fermi level position with respect to the intrinsic Fermi level at T = 300 K.

(4 marks)

(ii) Calculate the carrier concentrations and the Fermi level position with respect to the intrinsic Fermi level at T = 184 K and 575 K.

(8 marks)

(iii) From the answer in part **Q1(d)(i) – (ii)**, point out a simple conclusion based on the energy band diagram and carrier concentration.

(3 marks)

Q2 (a) Explain all the parameters that contribute towards total current density.

(5 marks)

(b) With the aid of a diagram, discuss the effect of lattice scattering and impurity scattering, towards mobility as a function of temperature.

(4 marks)

(c) Another technique for determining the conductivity type of a semiconductor is called the hot probe method. It consists of two probes and an ammeter that indicates the direction of the current. One probe is heated and the other is at room temperature. No voltage is applied, but a current will exist when the probes touch the semiconductor. With the aid of a diagram, explain the operation of the hot probe technique and relate it with carrier transport phenomena.

(4 marks)

(d) A GaAs semiconductor at T = 300 K is doped with multiple implants, which are 5.23×10^{14} antimony atoms/cm^3, 8.67×10^{16} gallium atoms/cm^3, 3.34×10^{14} phosphorus atoms/cm^3 and 4.56×10^{16} indium atoms/cm^3. Find the:

(i) carrier mobilities

(6 marks)

(ii) Conductivity and resistivity of the semiconductor.

(6 marks)

Q3 (a) With the aid of diagram, explain the following for a PN junction structure:

(i) the existence of an electric field formed in the space charge region.

(5 marks)

(ii) the size of space charge region width in one-sided PN junction.

(5 marks)

(iii) the existence of junction capacitance in PN junction.

(5 marks)

(b) For a silicon one-sided abrupt P^+N junction with $N_A = 4.34 \times 10^{14}$ cm^{-3} and $N_D = 3.27 \times 10^{18}$ cm^{-3} at zero bias and T = 550 K, calculate:

(i) built-in potential

(4 marks)

(ii) depletion layer width

(3 marks)

(iii) maximum electric field

(3 marks)

Q4 (a) With the aid of an energy band diagram, explain the MOS diode operation with p-type substrate in accumulation, depletion and inversion modes.

(6 marks)

(b) Sketch the structure of an n-channel enhancement mode MOSFET with the correct voltage connections. Label appropriately the source, drain, gate channel, V_{GS}, V_{DS} and the drain current I_D with the correct polarity and directions.

(7 marks)

(c) At room temperature consider a long-channel Silicon MOSFET with the following parameters,

$L = 2.3\ \mu m$ $Z = 8.6\ \mu m$ $\varepsilon_o = 8.85418 \times 10^{-14}$ F/cm $N_A = 6.45 \times 10^{14}\ cm^{-3}$
$\mu_n = 670\ cm^2/V\text{-}s$ $C_o = 3.54 \times 10^{-7}\ F/cm^2$ $V_T = 0.6$ V

Calculate the drain saturation voltage, V_{Dsat} and drain saturation current, I_{Dsat} for $V_G = 5.34$ V.

(6 marks)

(d) Discuss **TWO (2)** main approaches to overcome the problems arising from the scaling of MOSFET.

(6 marks)

-END OF QUESTIONS –

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Formulae

$$n = N_C \exp[-(E_C - E_F)/kT]$$

$$V_{Dsat} \cong V_G - 2\Psi_B + K^2\left(1 - \sqrt{1 + \frac{2V_G}{K^2}}\right)$$

$$p = N_V \exp[-(E_F - E_V)/kT]$$

$$K \equiv \frac{\sqrt{\varepsilon_s q N_A}}{C_o}$$

$$n = \frac{N_D - N_A}{2} + \left[\left(\frac{N_D - N_A}{2}\right)^2 + n_i^2\right]^{1/2}$$

$$I_{Dsat} \cong \left(\frac{Z\mu_n C_o}{2L}\right)(V_G - V_T)^2$$

$$p_n = n_i^{\,2} / n_n$$

$$E_F = E_i + kT \ln\left(\frac{n}{n_i}\right)$$

$$qV_{bi} = kT \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

$$E_F = E_i - kT \ln\left(\frac{p}{n_i}\right)$$

$$x_n + x_p = W \equiv \sqrt{\frac{2\varepsilon_S}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)V_{bi}}$$

$$\sigma = q(\mu_n n + \mu_p p)$$

$$\frac{1}{\mu} = \frac{1}{\mu_L} + \frac{1}{\mu_I}$$

$$J_N = q\mu_n E$$

$$E_{MAX} = \frac{qNW}{\varepsilon_S}$$

$$J_N = qD_n \frac{dn}{dx}$$

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Physical constant

Boltzmann constant, $k = 8.6173324 \times 10^{-5}$ eV/K or 1.38066×10^{-23} J/K

Thermal voltage at 300 K, $kT/q = 0.0259$ V

Permittivity in vacuum, $\varepsilon_o = 8.85418 \times 10^{-14}$ F/cm

Elementary charge, $q = 1.60218 \times 10^{-19}$ C

Properties of Si and GaAs at 300 K

Properties	**Si**	**GaAs**
Effective density of states in conduction band, N_C (cm^{-3})	2.86×10^{19}	4.7×10^{17}
Effective density of states in valence band, N_V (cm^{-3})	2.66×10^{19}	7.0×10^{18}
Dielectric constant	11.9	12.4
n_i (cm^{-3})	9.65×10^{9}	2.25×10^{6}
Energy gap (eV)	1.12	1.42
Mobility (cm^2/V-s)		
μ_n (electrons)	1450	9200
μ_p (holes)	505	320

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