UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2023/2024

COURSE NAME	:	FUNDAMENTAL OF SEMICONDUCTOR
COURSE CODE	:	BEJ 33103
PROGRAMME CODE	:	BEJ
EXAMINATION DATE	:	JULY 2024
DURATION	:	3 HOURS
INSTRUCTIONS	:	1. ANSWER ALL QUESTIONS 2. THIS FINAL EXAMINATION IS CONDUCTED VIA ☐ Open book ☒ 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

TERBUKA

Q1 Please answer the following questions.

(a) Sketch in only **ONE (1)** cubic unit cell which shows the following Miller Indices:

(i) [2 1 0] and [0 1 2]

(4 marks)

(ii) (1 1 0) and (0 1 2)

(4 marks)

(b) Explain, with the aid of diagram, the following statement:

(i) Semiconductor properties can be changed by doping.

(4 marks)

(ii) Activation energy in insulator is the highest compared to semiconductor and conductor.

(4 marks)

(iii) Fermi level energy is relevance to determine the semiconductor type.

(4 marks)

(c) At T = 300 K, calculate the carrier concentration when the extrinsic Fermi level is 0.36 eV above the valence band energy for silicon semiconductor.

(5 marks)

Q2 Please answer the following questions.

(a) With the aid of diagram, describe how a hole current can be obtained in an intrinsic semiconductor.

(4 marks)

(b) Consider a germanium sample at $T = 300$ °K with doping concentration of $N_d = 0$ and $N_a = 10^{16}$ cm^{-3}. The intrinsic carrier concentration, n_i is 2.4×10^{13} cm^{-3}. Assume complete ionization and electron and hole mobilities are 3900 cm^2/V·sec and 1900 cm^2 / V·sec. The applied electric field, E is 50 V/cm.

(i) Identify the type of the doped semiconductor and its majority carrier.

(2 marks)

(ii) Calculate the drift current density.

(4 marks)

(c) Consider an n-type semiconductor at temperature, T = 300 K, the electron concentration varies linearly from 2 x 10^{18} to 1 x 10^{17}/cm^3 over a distance of 0.4 cm. Given the electron diffusion coefficient is D_n = 100 cm^2/s, calculate the diffusion current density, $J_{n,diff}$.

(3 marks)

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

(i) carrier mobilities (using the graph in APPENDIX C)

(6 marks)

(ii) conductivity and resistivity of the semiconductor

(6 marks)

Q3 Please answer the following questions.

(a) For a PN junction structure, explain:

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

(5 marks)

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

(5 marks)

(b) Sketch a fully labelled diagram of each of the following distributions for an asymmetrical abrupt P$^+$N junction:

(i) carrier density.

(2 marks)

(ii) charge density.

(2 marks)

(iii) electric field.

(2 marks)

(iv) built-in potential.

(2 marks)

(c) Sketch the energy band diagram and circuit of a P-N junction for the following condition:

(i) Forward bias condition

(2 marks)

(ii) Reverse bias condition

(2 marks)

(d) A P-N junction has an asymmetrical depletion width and the electric field, E created is shown in Figure Q3.1. Identify which region has higher doping. State the reason.

(3 marks)

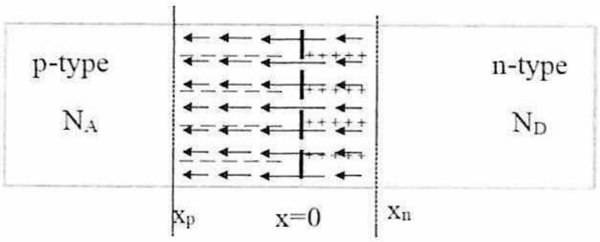


Figure Q3.1

Q4 Please answer the following questions.

(a) Describe what is meant by an inversion layer of charge and how an inversion layer of charge can be formed in a MOS capacitor with a p-type substrate.

(5 marks)

(b) Compare the basic operation of the MOSFET enhancement mode and depletion mode for n-channel devices.

(6 marks)

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

$L = 2.3\ \mu m$ $Z = 8.6\ \mu m$ $\varepsilon_0 = 8.85418 \times 10^{-14}$ F/cm

$N_a = 6.45 \times 10^{14}\ cm^{-3}$ $N_d = 4.24 \times 10^{12}\ cm^{-3}$ $\mu_n = 670\ cm^2/V\text{-}s$

$C_o = 3.54 \times 10^{-7}\ F/cm^2$ $V_T = 0.6$ V

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

(6 marks)

(d) Explain the following approaches to overcome the problems arising from the scaling of MOSFET:

(i) structure

(4 marks)

(ii) material

(4 marks)

- END OF QUESTIONS -

APPENDIX A LIST OF FORMULA

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

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

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

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

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

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

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

$$ni^2 = N_C N_V \left(\frac{T}{300}\right)^3 exp\left(\frac{-E_g}{kT\left(\frac{T}{300}\right)}\right)$$

$$\mathbf{J}_N = \mathbf{J}_{N|drift} + \mathbf{J}_{N|diff} = q\mu_n n\mathcal{E} + qD_N \frac{dn}{dx}$$

$$\mathbf{J}_P = \mathbf{J}_{P|drift} + \mathbf{J}_{P|diff} = q\mu_p p\mathcal{E} - qD_P \frac{dp}{dx}$$

$$\rho = \frac{1}{q\mu_n n + q\mu_p p}$$

$$W \approx \sqrt{\frac{2\varepsilon_S}{q}\frac{V_{bi}}{N}}$$

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

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

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

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

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

APPENDIX B

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

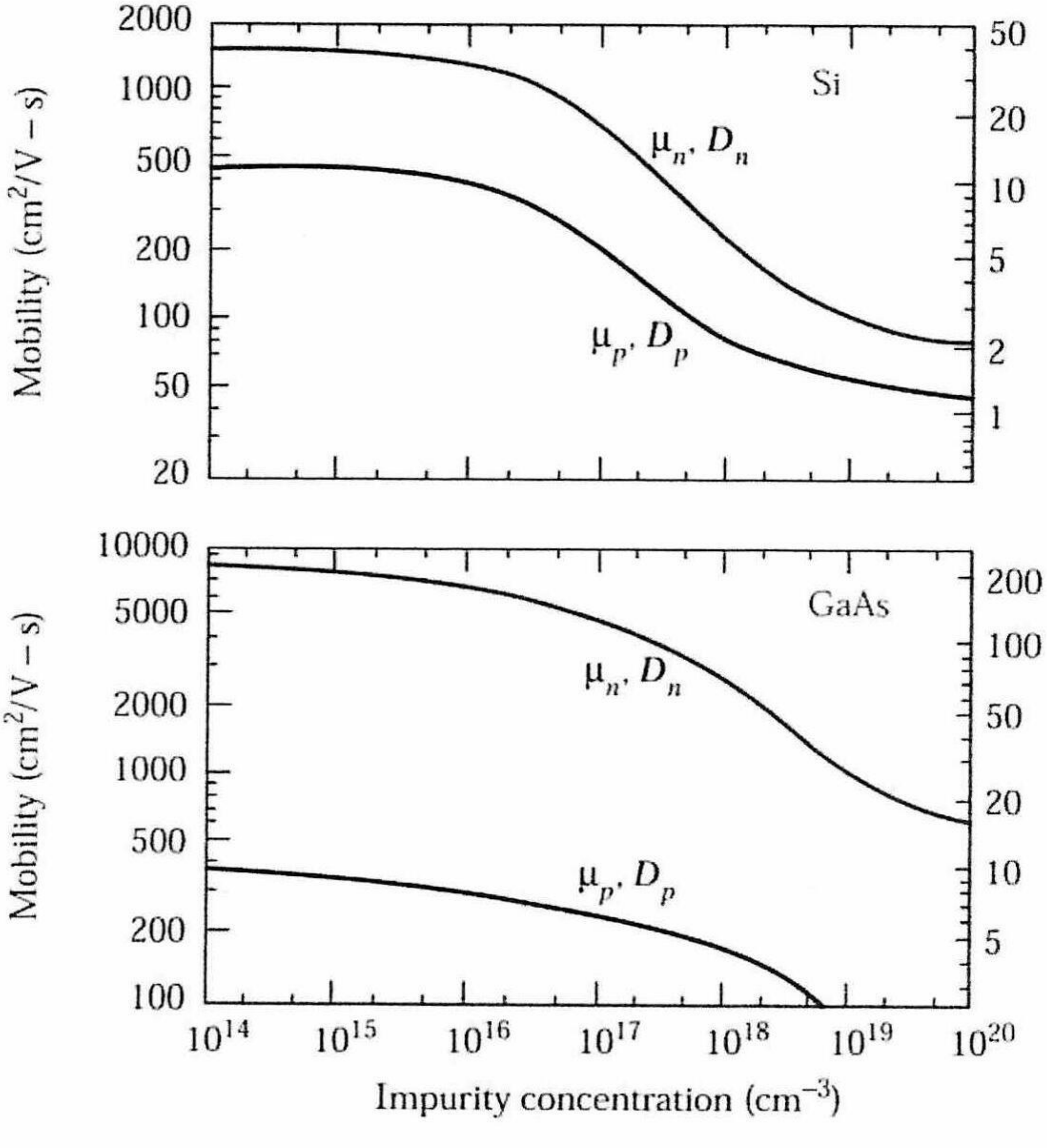
Permittivity in vacuum, $\varepsilon_o = 8.85418 \times 10^{-14}$ F/cm

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

APPENDIX C


2000
1000
500
200
100
50
20
Mobility (cm^2/V – s)
50
20
10
5
2
1
Mobility (cm^2/V – s)
Si
μ_n, D_n
μ_p, D_p
10000
5000
2000
1000
500
200
100
Mobility (cm^2/V – s)
200
100
50
20
10
5
Diffusivity (cm^2/s)
GaAs
μ_n, D_n
μ_p, D_p
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
Impurity concentration (cm^{-3})