UTHM
Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2016/2017

COURSE NAME : SEMICONDUCTOR ELECTRONIC AND DEVICES

COURSE CODE : BED 20103

PROGRAMME : BEJ

EXAMINATION DATE : DECEMBER 2016 / JANUARY 2017

DURATION : 2 HOURS AND 30 MINUTES

INSTRUCTION : ANSWER **ALL** QUESTIONS

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

Q1 (a) Sketch the band diagram of an ideal MOS diode with *p*-type substrate at $V_G > 0$ V under inversion condition

(2 marks)

(b) Analyse the following terms by referring to the band diagram sketched in **Q1(a)**

(i) the charge distribution

(3 marks)

(ii) the electric-field distribution

(3 marks)

(iii) the potential distribution

(3 marks)

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

$L = 3\ \mu m$ $Z = 9\ \mu m$ $\varepsilon_s = 8.85418 \times 10^{-14}$ F/cm $N_A = 2 \times 10^{14}\ cm^{-3}$

$\mu_n = 600\ cm^2/V\text{-}s$ $C_o = 3.54 \times 10^{-7}\ F/cm^2$ $V_T = 0.6$ V

Analyse drain saturation voltage, V_{Dsat} and drain saturation current, I_{Dsat} for $V_G = 6V$

(6 marks)

(d) FinFET and graphene are two difference approaches in order to overcome the problems arising from scaling MOSFET. Justify this statement

(8 marks)

Q2 (a) Describe the motion of electrons and holes when p- and n-type semiconductors are jointed together. Appropriate diagram may be used to support your answer.

(4 marks)

(b) (i) Define built-in potential of a P-N junction.

(2 marks)

(ii) Sketch the potential distribution for equilibrium, forward bias and reverse bias conditions of PN junction in one diagram.

(3 marks)

(c) Describe **TWO (2)** physical mechanisms that give rise to the reverse bias breakdown in PN junction.

(4 marks)

(d) For a silicon one-sided abrupt p-n junction with $N_D = 4 \times 10^{17}$ cm^{-3} and $N_A = 3 \times 10^{14} cm^{-3}$ at zero bias, analyse

(i) built-in potential at 500K

(4 marks)

(ii) depletion layer width (T = 500 K)

(4 marks)

(iii) maximum electric field (T = 500 K)

(4 marks)

Q3 (a) Draw **ONE (1)** energy band diagram of a compensated semiconductor showing clearly the followings:

(i) Ionized and unionixed donors and acceptors,

(ii) Donor electrons and acceptor holes, and thermal electrons and holes

(iii) Donor electrons recombine with acceptor holes

(5 marks)

(b) Explain with the aid of suitable figures, the difference (energy band) between insulator, conductor and semiconductor.

(9 marks)

(c) A Silicon (Si) sample is doped with 10^{14} boron per cm^3:

(i) Calculate the carrier concentrations in the Si sample at 300K

(2 marks)

(ii) Calculate the carrier concentrations at 470K given $n_i = 10^{14}/ cm^3$

(2 marks)

(iii) For each of the conditions above, calculate $E_f - E_i$ and draw the energy band diagram for the Si sample.

(4 marks)

(iv) From the answer in **Q3(c)(i) – (iii)**, give a simple conclusion based on energy band diagram and carrier concentration

(3 marks)

Q4 (a) In a semiconductor, current is caused by electron transport. Explain the following:

(i) The differences between carrier drift and diffusion

(4 marks)

(ii) The relation between carrier drift and diffusion

(2 marks)

(iii) **TWO (2)** transport phenomena that affect the current flow indirectly

(4 marks)

(b) Calculate the hole and electron concentrations, mobility and resistivity for silicon doped with 1.3×10^{16} boron/cm^3 and 1.5×10^{15} phosphorus/cm^3 at 300K.

(5 marks)

(c) Consider an n-type semiconductor at temperature, $T = 300$ K, the electron concentration varies linearly from 2×10^{18} to 6×10^{17}/cm^3 over a distance of 0.2 cm. Given the electron diffusion coefficient is $D_n = 25$ cm^2/s, calculate the diffusion current density, $J_{n,\ diff}$.

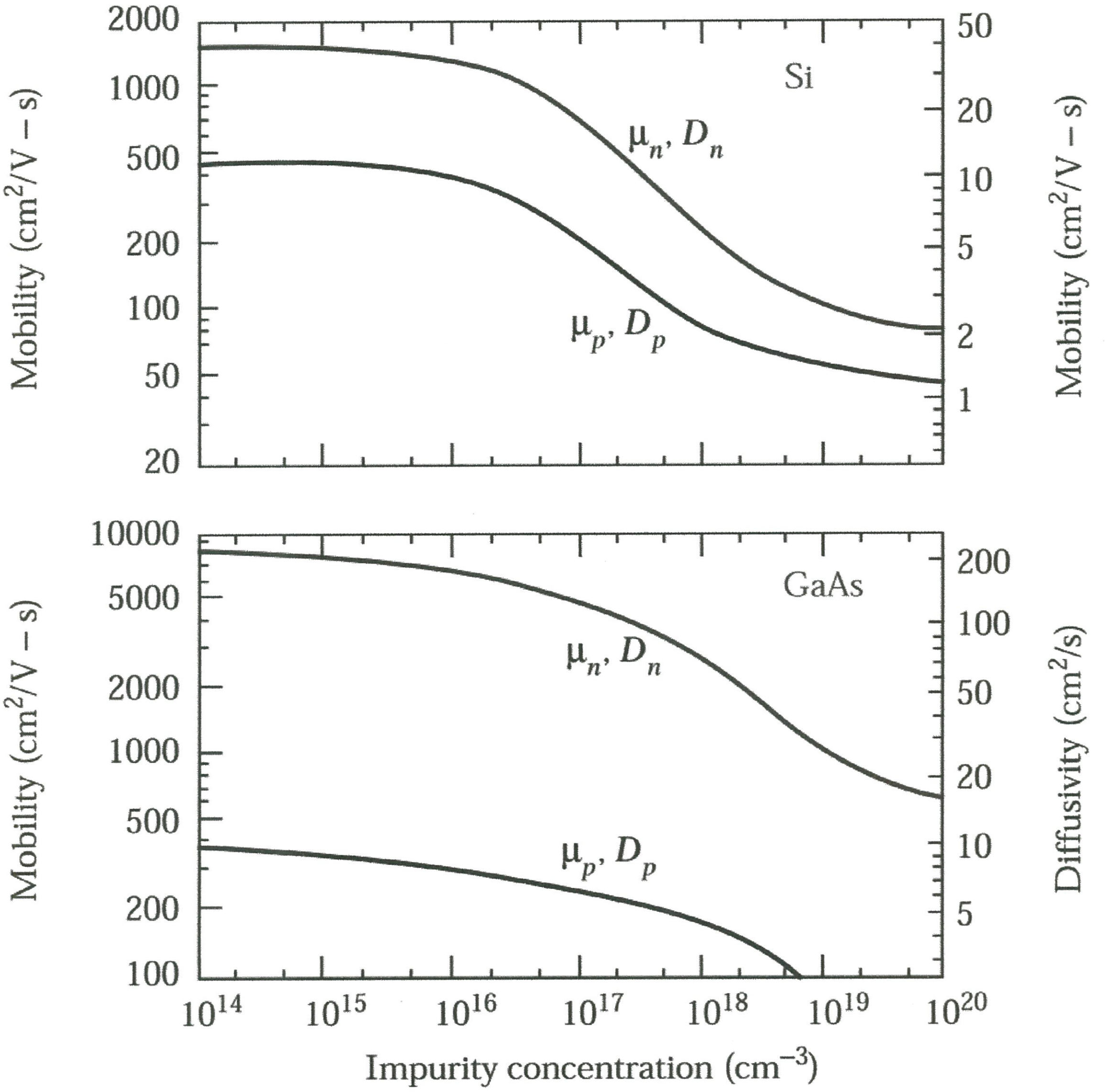
(5 marks)

(d) Two scattering mechanisms exist in semiconductors which are lattice scattering and impurity scattering. If only the first mechanism is present, the mobility will be 200cm^2/V-s. If only the second mechanism is present, the mobility will be 550cm^2/V-s. Calculate the mobility when both scattering mechanisms exist at the same time.

(5 marks)

- END OF QUESTIONS -

APPENDIX



A1. Mobilities and diffusivities in Si and GaAs at 300 K as a function of impurity concentration.

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Formulae

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

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

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

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

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

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

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

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

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

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

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

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

$$I_D \cong \frac{Z}{L}\mu_n C_o (V_G - V_T) V_D$$ For $V_D << (V_G - V_T)$

$$V_T = \frac{\sqrt{2\varepsilon_s q N_A (2\psi_B)}}{C_o} + 2\psi_B$$

$$g_D \equiv \frac{\partial I_D}{\partial V_D}\bigg|_{V_G = \text{constant}} \cong \frac{Z}{L}\mu_n C_o (V_G - V_T)$$

$$g_m \equiv \frac{\partial I_D}{\partial V_G}\bigg|_{V_D = \text{constant}} \cong \frac{Z}{L}\mu_n C_o V_D$$

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

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

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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, $kT/q = 0.025852$ 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