UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

MAIN EXAMINATION 2010

TITLE OF PAPER: ELECTRONIC MATERIALS & DEVICES II

COURSE NUMBER: E 450

TIME ALLOWED : THREE HOURS

INSTRUCTIONS TO CANDIDATES:

USEFUL DATA AND FORMULAE ARE IN THE APPENDIX.

ANSWER ANY **FOUR** QUESTIONS . ALL QUESTIONS CARRY EQUAL MARKS

THIS PAPER IS NOT TO BE OPENED UNTIL PERMISSION HAS BEEN GIVEN BY THE INVIGILATOR.

Question One.

(a) (i) Draw a sketch of the current - voltage characteristics of an n-channel JFET for different values of the gate voltage. (3 marks)

(ii) Explain the main features of the current - voltage characteristic for the case in which no gate voltage is applied . (4 marks)

(iii) State two reasons why a FET is preferred to a BJT. (2 marks)

(b) The drain current of a JFET is given as

$$I_D = G_0\left\{V_D - \frac{2}{3}V_P\left[\left(\frac{V_i - V_G + V_D}{V_P}\right)^{3/2} - \left(\frac{V_i - V_G}{V_P}\right)^{3/2}\right]\right\},$$

where the symbols have their usual meanings.

(i) Show that in the linear region, the above expression becomes

$$I_D = G_0\left[1 - \left(\frac{V_i - V_g}{V_p}\right)^{1/2}\right]V_D .$$

[Hint: expand the term containing V_D using binomial series]

(6 marks)

(ii) Define the ***threshold voltage*** V_{th} of a JFET and show that it is equal $V_i - V_p$.

(5 marks)

(iii) Define ***transconductance*** of a JFET and obtain an expression for it.

(5 marks)

[25]

Question Two

(a) (i) Explain what is meant by Base-width modulation in a transistor. (3 marks)

(ii) Discuss the effects of base- width modulation in the performance of a real p-n-p transistor in normal operation.

(5 marks)

(b) The punch - through voltage of a germanium p-n-p transistor is 25V. The base doping is 10^{15} cm^{-3}. The emitter and collector dopant concentrations are 10^{19} cm^{-3} each. Calculate

(i) the built-in voltage, (3 marks)

(ii) the zero bias base width, (4 marks)

(iii) the common emitter current gain β, and (8 marks)

(iv) the common base current gain α for a reverse bias of 10 V across the collector-base junction. (2 marks)

Assume $\tau_B = 10^{-6}$s, n_i for Ge = 2.4×10^{13} cm^{-3}, T= 300 K

[25]

Question Three

(a) A small signal ac voltage is superimposed on the dc bias of a p-n-p diffusion transistor in the normal operation. Neglecting the depletion region charges show that the small signal common base current gain of the transistor can be written as

$$\alpha(\omega) = \frac{\alpha_0}{1 + \dfrac{j\omega}{\omega_\alpha}}$$

where symbols have their usual meanings. (9 marks)

Given:

$$i_E = (Q_N + q_N)\left(\frac{1}{\tau_N} + \frac{1}{\tau_{BN}}\right) + \frac{d}{dt}\left(Q_N + q_N\right); i_C = -\frac{Q_N + q_N}{\tau_N}$$

Hint: assume that the charge associated with the ac voltage is of the form $q_N = q_{N0}\exp(j\omega t)$

(b) Given that the beta cut - off frequency $f_\beta = f_\alpha(1 - \alpha_o)$ show that the common emitter current gain can be expressed as:

$$\beta(\omega) = \frac{\beta_0}{1 + \dfrac{jf}{f_\beta}}$$

(7 marks)

(c) A transistor operating at 20 MHz has current gain $\beta = 20$. Neglecting junction capacitance and series resistance, calculate:

(i) the beta cut-off frequency f_β (4 marks)
(ii) the alpha cut - off frequency f_α (3 marks)
(iii) the gain bandwidth frequency f_T (2 marks)

[Given that $\beta_0 = 100$]

[25]

Question Four.

(a) (i) Give details of the Float-Zone method in the fabrication of single crystal silicon wafer with the help of a schematic diagram of the set up.

(ii) State the advantages of Float-zone technique over the Czochralski method of wafer
preparation.

(10 marks)

(iii) What is zone refining? Explain. (4 marks)

(iv) Explain the process of neutron transmutation doping mentioning its importance. (4 marks)

(b) A silicon crystal doped with phosphorus is pulled from its melt . Calculate how many grams of phosphorus should be added to 1 kg of silicon to get a donor concentration of 10^{16} cm^{-3} during the initial growth. The distribution coefficient of phosphorus is 0.35. Atomic weight of phosphorus is 30.97, density of silicon is 2.53 g cm^{-3}.

(7 marks)

[25]

Question Five

(a) A, B, C, and D are four points on the periphery of an odd- shaped semiconductor sample of thickness 0.2 mm. Following are the results obtained in the van der Paw method for resistivity measurements on the sample.

$V_{Dc} = 5V$, $V_{Bc} = 10V$, $I_{AB} = 50$ mA, $I_{AD} = 200$ mA.

Calculate the resistivity and sheet resistance of the sample. (8 marks)

(b) The hole mobility of the sample in question (a) above is 400 cm^2/Vs. Determine the Hall voltage V_{BD} developed across the points B and D of the sample when it is placed in a magnetic field of $5x10^{-5}$ Wb cm^{-2} and 5 mA current is passed across A and C.

(7 marks)

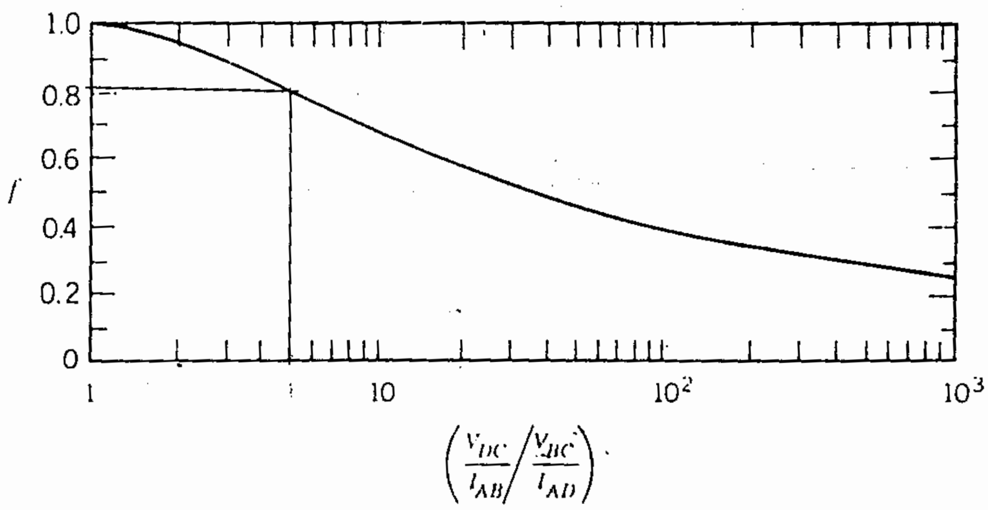
(c) In a Haynes- Shockley experiment the following data were obtained in a semiconductor sample of length 2 cm.

$x_o = 1$ cm
$V_1 = 10V$
$t_o = 200\ \mu s$
$\Delta t = 30\ \mu s$

(i) Calculate the mobility and the diffusion coefficient of the minority carriers.

(ii) Verify whether or not your results agree with Einstein's relation. (T=300K) (10 marks)

APPENDIX A



Correction factor for van der Pauw arrangement.

APPENDIX B
PHYSICAL CONSTANTS

Quantity	Symbol	Value
Angstrom unit	Å	1 Å = 10^{-8} cm = 10^{-10} m
Avogadro number	N	6.023×10^{23}/mol
Boltzmann constant	k	8.620×10^{-5} eV/K = 1.381×10^{-23} J/K
Electronic charge	q	1.602×10^{-19} C
Electron rest mass	m_o	9.109×10^{-31} kg
Electron volt	eV	1 eV = 1.602×10^{-19} J
Gas constant	R	1.987 cal/mole-K
Permeability of free space	μ_o	1.257×10^{-6} H/m
Permittivity of free space	ε_o	8.850×10^{-12} F/m
Planck constant	h	6.626×10^{-34} J-s
Proton rest mass	m_p	1.673×10^{-27} kg
$h/2\pi$	$\hbar$	1.054×10^{-34} J-s
Thermal voltage at 300 K	V_T	0.02586 V
Velocity of light in vacuum	c	2.998×10^{10} cm/s
Wavelength of 1-eV quantum	λ	1.24 μm

TABLE 4.2
Properties of Ge, Si and GaAs at 300 K

Property	Ge	Si	GaAs
Atomic/molecular weight	72.6	28.09	144.63
Density (g cm^{-3})	5.33	2.33	5.32
Dielectric constant	16.0	11.9	13.1
Effective density of states			
Conduction band, N_C (cm^{-3})	1.04×10^{19}	2.8×10^{19}	4.7×10^{17}
Valence band N_V (cm^{-3})	6.0×10^{18}	1.02×10^{19}	7.0×10^{18}
Electron affinity (eV)	4.01	4.05	4.07
Energy gap, E_g (eV)	0.67	1.12	1.43
Intrinsic carrier			
concentration, n_i (cm^{-3})	2.4×10^{13}	1.5×10^{10}	1.79×10^{6}
Lattice constant (Å)	5.65	5.43	5.65
Effective mass			
Density of states m_e^*/m_o	0.55	1.18	0.068
m_h^*/m_o	0.3	0.81	0.56
Conductivity m_e/m_o	0.12	0.26	0.09
m_h/m_o	0.23	0.38	
Melting point (°C)	937	1415	1238
Intrinsic mobility			
Electron (cm^2 V^{-1} sec^{-1}), μ_n	3900	1350	8500
Hole (cm^2 V^{-1} sec^{-1}), μ_p	1900	480	400

APPENDIX A

Some useful equations.

$$I_D = G_0\left\{V_D - \frac{2}{3}V_P\left[\left(\frac{V_i - V_G + V_D}{V_P}\right)^{3/2} - \left(\frac{V_i - V_G}{V_P}\right)^{3/2}\right]\right\}$$

$$f_{\max} = \left[\frac{f_T}{8\pi r_B C_c}\right]^{1/2}$$

$$W_B = W_{B0} - \left[\frac{2\varepsilon_S}{qN_d}(V_i - V_{CB})\right]^{1/2}$$

$$\omega_\alpha = \frac{2.43 D_B}{\omega_B^{\,2}}\left[1 + \left(\frac{\eta}{2}\right)^{4/3}\right]$$

$$\frac{I_{NE}}{I_{PE}} = \frac{N_D D_E L_B \tanh(W_B / L_B)}{N_a D_B L_E \tanh(W_E / L_E)}$$

$$\alpha(\omega) = \frac{\alpha_0}{1 + j\omega / \omega_\alpha}\exp\left(-j\frac{m\omega}{\omega_\alpha}\right)$$

$$G_E \approx \frac{N_a L_E}{D_E}$$

$$\rho = \frac{\pi d}{2\ln 2}\left(\frac{V_{DC}}{I_{AB}} + \frac{V_{BC}}{I_{AD}}\right)f$$