UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRONIC ENGINEERING

MAIN EXAMINATION 2006/2007

TITLE OF PAPER: ELECTRONIC MATERIALS & DEVICES II

COURSE NUMBER: E 450

TIME ALLOWED : THREE HOURS

<u>INSTRUCTIONS TO CANDIDATES:</u>

USEFUL DATA AND FORMULAE ARE ATTACHED
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 the circuit diagram of a p-n-p transistor operating under normal active mode, clearly indicating all current components. (3 marks)

(ii) State what each term represent in the equation for the common emitter current gain $\alpha = \gamma\alpha_T M$ of the transistor. Express them in terms of the current components.

(3 marks)

(iii) What design considerations would you recommend to obtain high values of the current gain? (3 marks)

(b) There are four regions of operation for a bipolar p-n-p transistor corresponding to the four possible combinations of the emitter - base (V_{EB}) and collector - base (V_{CB}) applied voltages. Describe how the transistor operates in each of these regions. (Draw necessary diagrams)

(8 marks)

(c) A p-n-p transistor has impurity concentrations of 5×10^{15} cm^{-3} in the base and 5×10^{18} cm^{-3} in the emitter and collector regions. The base width, W_B is 10 μm. The minority carrier life time in the base and emitter (τ_B and τ_E) are 4×10^{-6}s and 10^{-8}s respectively. The emitter region is much longer than the emitter diffusion length L_E. The base width is much smaller than the base diffusion length L_B. Minority carrier diffusion coefficients in the base and emitter (D_B and D_E) are 47 cm^2 s^{-1} and 52 cm^2 s^{-1} respectively.

Calculate the current gains α and h_{FE} of the transistor. (Assume that the collector multiplication factor M=1)

(8 marks)

Question Two.

(a) Explain the features of a drift transistor as compared to a diffusion transistor.
(3 marks)

(b) Given below is the expression for the emitter current due to holes in a drift transistor.

$I_{PE} = \frac{qAn_i^2}{G_B}\left[\exp(V_{EB}/V_T) - 1\right]$, where G_B is the base Gummel number.

Write down the equivalent expression for the electron current in terms of the emitter Gummel number. Hence derive equations for the emitter efficiency and the common emitter current gain of the transistor in terms of the Gummel numbers.
(10 marks)

(c) A drift transistor has base width $W_B = 1.5\ \mu m$, minority carrier diffusion coefficient in the base $D_B = 7\ cm^2s^{-1}$ and cut-off frequency $f_\alpha = 450$ MHz. Given $\alpha_0 = 0.9$.
Calculate:

(i) the excess phase factor m (6 marks)
(ii) the common base current gain $\alpha(\omega)$ at 300 MHz (6 marks)

[see appendix for useful equations]

Question Three

(a) Draw a labelled schematic diagram of an n-channel junction field-effect transistor (JFET) showing the biasing arrangement.
Explain what is meant by *conductance modulation* and hence distinguish between a Junction FET and a Surface FET.

(12 marks)

(b) A double-gate n-channel silicon JFET has $N_d = 5 \times 10^{21}\ m^{-3}$, $N_a = 10^{25}\ m^{-3}$, total channel thickness $2a = 2\ \mu m$, channel length $L = 30\ \mu m$, channel width $Z = 10^{-3}\ m$, electron mobility $\mu_n = 0.105\ m^2 / V\text{-}s$. Calculate:

(i) the pinch-off voltage
(ii) the drain current for $V_D = 0.5V$ and $V_G = -1V$. Assume T = 300 K.
(iii) the threshold voltage and state what is its significance.

(13 marks)

Question Four

(a) (i) Give technical details of photolithography. (4 marks)

(ii) Discuss e-beam evaporation for metal deposition on semiconductors. (4 marks)

(b) (i) Draw the schematic diagram of the Czochralski method for single crystal wafer preparation of silicon. (4 marks)

(ii) With the help of a schematic diagram of the set up, describe the Float-Zone method for the fabrication of single crystal silicon wafer.
State the advantages of this technique over the Czochralski method of wafer preparation. (10 marks)

(iii) What is zone refining? Explain. (3 marks)

Question Five

(a) A B C 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.

$V_{Dc} = 4V$, $V_{Bc} = 10V$, $I_{AB} = 40$ 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)

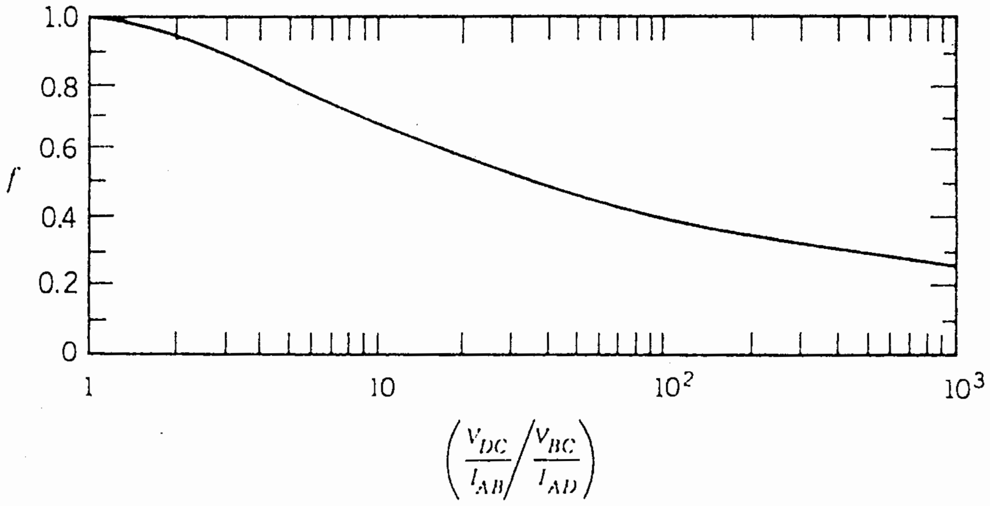
(c) In a Haynes- Shockley experiment the following data were obtained in a semiconductor sample of length 2 cm.

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

(i) Calculate the mobility , diffusion coefficient of the minority carriers

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

APPENDIX A



The correction factor *f* for the 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
$h/2\pi$	h	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

APPENDIX C

Some useful equations.

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

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

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

For a BJT ,

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

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

Drift Transistors:

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

van der Pauw, Hall effect.:

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

$$R_H = \frac{V_{BD}d}{I_{AC}B} = \mu_H \rho$$