UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRONIC ENGINEERING

MAIN EXAMINATION 2007/2008.

TITLE OF PAPER: ELECTRONIC MATERIALS & DEVICES II

COURSE NUMBER: E450

TIME ALLOWED : THREE HOURS

INSTRUCTIONS TO CANDIDATES:

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) Distinguish between **transit time** (τ_B)and **life time** (τ_N)of a charge carrier in the base of a Bipolar Junction Transistor (BJT).
State why the transit time is generally much less than the life time. (3 + 1 marks)

(ii) Calculate the common emitter current gain of a BJT having transit time of 10 μs and life time of 0.1 μs. (2 marks)

(b) Given below are the Ebers- Moll equations of a bipolar junction transistor.

$$I_E = -I_{ES}\left[\exp\left(\frac{V_{EB}}{V_T}\right) - 1\right] + \alpha_I I_{CS}\left[\exp\left(\frac{V_{CB}}{V_T}\right) - 1\right]$$

$$I_C = -\alpha_N I_{ES}\left[\exp\left(\frac{V_{EB}}{V_T}\right) - 1\right] - I_{CS}\left[\exp\left(\frac{V_{CB}}{V_T}\right) - 1\right]$$

(i) Write down the reciprocity relation in transistors stating what each term represent. (3 marks)

(ii) Show how the proportionality factor I_{CS} can be expressed in terms of the reverse saturation currents at the collector - base junction.
(6 marks)
(Hint: Rearrange the Ebers-Moll equation with emitter leads open)

(c) A p-n-p transistor has I_{ES} = -2 μA, I_{CS} = -3 μA and α_N = 0.95. It is connected to a battery with positive to the emitter and negative to the collector. The base is open circuited. Calculate the emitter current.
(10 marks)

(Hint: Modify the E-M equations for a reverse biased C-B junction and let $I_B + I_C = 0$)

<u>Question Two.</u>

(a) A p-n-p diffusion transistor with abrupt junctions is operating under normal active mode.

(i) Draw the biasing arrangement showing the emitter, base and collector currents. (3 marks)

(ii) Write down the emitter, base and collector currents in terms of the current components due to electron and hole flow across the transistor. (3 marks)

(iii) Draw the energy band diagram of the transistor. (3 marks)

(b) Small signal common base current gain of a p-n-p diffusion transistor is given as:

$$\alpha(\omega) = \frac{\alpha_0}{1 + \frac{j\omega}{\omega_\alpha}}$$, where symbols have their usual meanings.

(i) Write down the values of α_o and ω_α in terms of the life time and transit time of the holes in the base. (2 marks)

(ii) 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:

$$\beta(\omega) = \frac{\beta_0}{1 + \frac{jf}{f_\beta}}$$ (5 marks)

(iii) Define current gain band width frequency f_T (2 marks)

(iv) Show that $f_T = \alpha_o f_\alpha$ (Take $\beta_0 >> 1$) (3 marks)

(c) (i) What is meant by maximum frequency f_{max} of a transistor? (2 marks)

(ii) A transistor has current gain bandwidth frequency of 408 MHz, collector junction capacitance 3 pF and base resistance 25 Ω. Calculate the maximum frequency f_{max} of the transistor (2 marks)

Question Three

(a) (i) Draw a schematic diagram showing the structure and biasing of a Junction Field effect Transistor (JFET). (4marks)

(ii) Explain how the channel of a JFET get pinched-off by increasing the drain voltage (no gate voltage applied). (4marks)

(ii (i) Define *drain conductance* and *transconductance* of a JFET. (2 marks)

(ii) Show that the drain conductance in the linear region can be expressed as:

$$G_D = G_0\left[1-\left(\frac{V_i - V_G}{V_P}\right)^{1/2}\right]$$

given: $I_D = G_0\left\{V_D - \frac{2}{3}V_P\left[\left(\frac{V_i - V_G + V_D}{V_P}\right)^{3/2} - \left(\frac{V_i - V_G}{V_P}\right)^{3/2}\right]\right\}$ (10 marks)

(iii) What is *threshold voltage* V_{th} a JFET? Show that $V_{th} = V_i - V_p$ (5 marks)

Question Four.

(a) (i) With the help of a schematic diagram, explain the Float-Zone method in the fabrication of single crystal silicon ingots. (8 marks)

(ii) Describe how silicon wafers are prepared for device fabrication from the ingots. (4 marks)

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

(b) (i) What is epitaxial growth of semiconductors? (2 marks)

(ii) With the help of a schematic diagram describe the molecular beam epitaxy method for growing doped AlGaAs layers on GaAs. (8 marks)

<u>Question Five.</u>

(a) (i) Draw schematic diagram of the four-point probe set up for measurement of resistivity of a semiconductor sample. (3 marks)

(ii) A 0.2 mm thick semiconductor wafer has diameter of 2.0 cm. It is placed on an insulating plate. Four point probe readings at the centre of the wafer are V= 50 mV and I = 0.5 mA. The spacing between the probes is 0.4 mm. Determine the resistivity and sheet resistance of the wafer. (see appendix C for correction factors). (9 marks)

(b) (i) Draw a labeled schematic diagram of the Haynes-Shockley experimental set up for finding the drift mobility of minority carriers in an n-type semiconductor. (5 marks)

(ii) The following data were obtained in a Hanes - Shockley experiment. at 300 K

Length of the sample	=	2.5 cm.
Spacing between the emitter and collector	=	1.0 cm
Voltage applied across the sample	=	20 V
Time of arrival of the pulse at the collector	=	1.5×10^{-4} s

1. Calculate the mobility of the minority carriers in the sample.
2. Use Einstein's equation to find the diffusion coefficient of the carriers.

(8 marks)

APPENDIX A

Some useful equations.

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

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

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

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.:

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

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

8/-

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

APPENDIX C

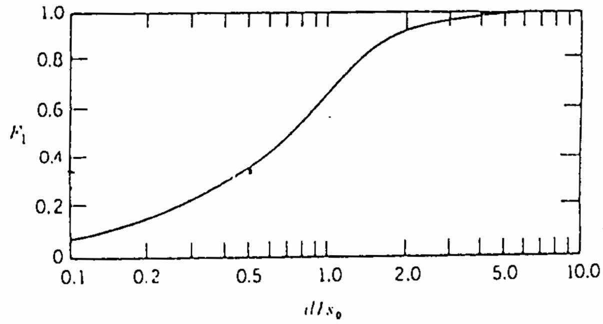

FIGURE 20.3 Correction factor F_1 for a thin wafer placed on a nonconducting surface as a function of d/s_0. (From G. Knight Jr., Measurement of semiconductor parameters, in *Handbook of Semiconductor Electronics*, L. P. Hunter (ed.), p. 20.4. Copyright © 1962. Reprinted by permission of McGraw-Hill, Inc., New York.)

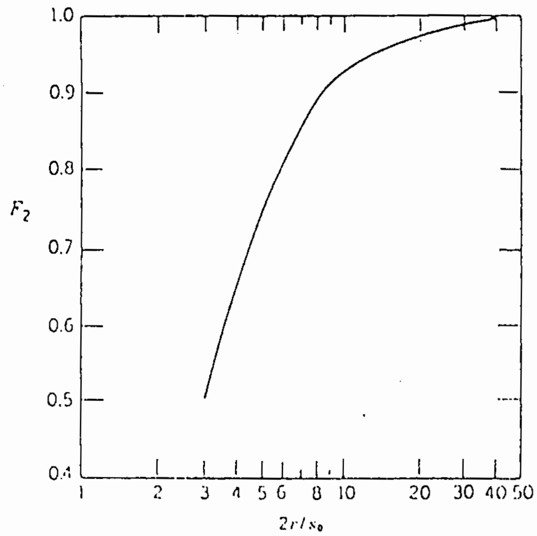

FIGURE 20.4 Correction factor F_2 for probes centered on a circular wafer of finite diameter $2r$ as a function of the ratio $2r/s_0$. (From F. M. Smits, Measurement of sheet resistivities with four-point probe, *Bell Syst. Tech. J.* vol. 37, part :, May 1958: Table III, p. 716. Reprinted with permission. Copyright © 1958 AT&T.)