UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRONIC ENGINEERING

MAIN EXAMINATION 2008/2009

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 the circuit diagram of a p-n-p transistor showing the biasing and all current components when it is operating in the normal active mode. State what each current component represent. (4 marks)

(ii) Consider a p-n-p transistor biased in the normal active region of operation at room temperature. The base current and collector currents I_B and I_c are negative. If I_c is held constant and the temperature is raised I_B will become positive. Explain this in terms of the physical phenomena that occur in the device. (5 marks)

(b) A p-n-p transistor has impurity concentrations of $5x10^{15}$ cm^{-3} in the base and $5x10^{18}$ 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 $4x10^{-6}$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, see appendix for useful equations)

(10 marks)

(c) A real transistor differs from an intrinsic transistor in several ways. Discus fully with equations where necessary, the effect of variation of the collector - base voltage in the operation of a real transistor. (6 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) Discuss the bipolar isolation technique used in IC fabrication. (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) (i) Describe the "hot probe " method to determine the conductivity type of a semiconductor sample. (3 marks)

(ii) A semiconductor wafer has thickness of $2x10^{-4}$ m and a diameter of $2.5x10^{-2}$ m. A four-point probe measurement made in the center of the wafer has V/I = 80 Ω The spacing between the probes is $5x10^{-4}$ m. Determine the resistivity and the sheet resistance of the wafer using appropriate correction factors from appendix. (6 marks)

(b) (i) With the help of a schematic diagram briefly describe the photoconductivity decay method for finding the minority carrier life time in semiconductors. (10 marks)

(ii) In a typical lifetime measurement, the dark resistance of a sample is 200 Ω and the resistance of the illuminated sample just before removing the light is 180 Ω. Assume a constant current of 2 mA and the time constant for the decay of the voltage $\tau_V = 0.5\mu s$. Calculate the bulk lifetime. (6 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.:

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

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

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

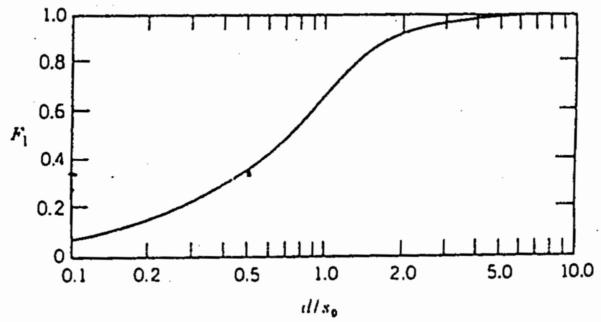

FIGURE 20.3 Correction factor F_1 for a thin wafer placed on a nonconducting surface as a function of d/s_0. (From G. Knight Jr., Measurement of semiconductor parameters, in *Handbook of Semiconductor Electronics*, L. P. Hunter (ed.), p. 20.4. Copyright © 1962. Reprinted by permission of McGraw-Hill,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

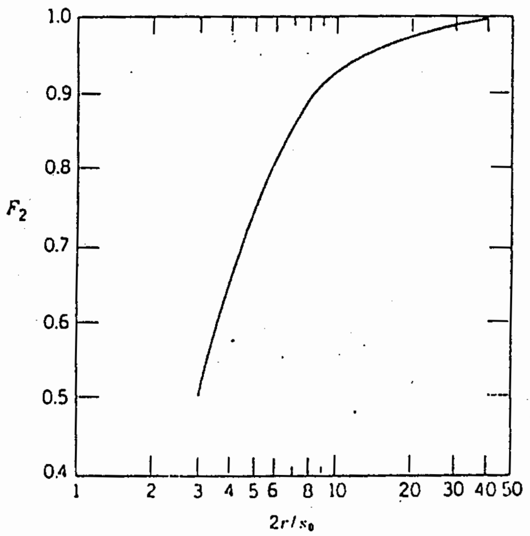

FIGURE 20.4 Correction factor F_2 for probes centered on a circular wafer of finite diameter $2r$ as a function of the ratio $2r/s_0$. (From F. M. Smits, Measurement of sheet resistivities with four-point probe, *Bell Syst. Tech. J.* vol. 37, part [illegible], May 1958. Table III, p. 716. Reprinted with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