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UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRONIC ENGINEERING

MAIN EXAMINATION 2005

TITLE OF PAPER: ELECTRONIC MATERIALS & DEVICES II

COURSE NUMBER: E 450

TIME ALLOWED : THREE HOURS

ANSWER ANY FOUR QUESTIONS . ALL CARRY EQUAL MARKS

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

Question One.

(a) Show that for a p-n-p transistor in normal operation, the common emitter current gain can be expressed as:

$$h_{FE} = \frac{\tau_B}{\tau_N}$$

where τ_B and τ_N are the hole life time and hole transit time in the base respectively.

Hints: Assume a linear decrease in the hole distribution in the base.
Neglect the reverse saturation current I_{CO}.
Electron emitter current I_{nE} is small compared to the recombination current I_{Pr}.

(11 marks)

(b) An n-p-n transistor at 300 K has common emitter d.c. current gain $\beta_0 = 100$, and its β cut-off frequency is 20.4 MHz. Assuming that its emitter efficiency $\gamma = 1$ and that the base is uniformly doped and $D_B = 12\ \text{cm}^2\ \text{s}^{-1}$, calculate:

(i) the current gain β at 100 MHz. (5 marks)
(ii) the α cut- off frequency. (3 marks)
(iii) the current gain band width frequency. (2 marks)
(iv) the base width. (4 marks)

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Question Two.

(a) 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)

(b) The donor concentration in the base region of a silicon p-n-p transistor is given as: $N_d(x) = 2 \times 10^{18} \exp(-x/\lambda)$ m^{-3}, where $\lambda = 1.2\mu$m. The transistor has base width $W_B = 4.5\mu$m, emitter width $W_E = 2.5\mu$m and a uniform dopant concentration $N_a = 5 \times 10^{18}$ m^{-3} in the emitter.

Calculate:

(i) the base Gummel number.

(ii) the emitter Gummel number.

(iii) the common emitter current gain.

Assume $D_B = 8 \times 10^{-4}$ m^{2}s^{-1}, $D_E = 2.5 \times 10^{-4}$ m^{2}s^{-1}, $\tau_B = 2 \times 10^{-7}$s, $\tau_E = 1.5 \times 10^{-8}$ s, and T = 300 K.

Given: $$G_B = \int_0^{W_B} \frac{N_d(x)}{D_B} dx.$$ (15 marks)

Question Three.

(a) Explain the terms ***saturation voltage*** and ***pinch off voltage*** of a junction field effect transistor. (10 marks)

(b) An double gate silicon n-channel junction field effect transistor at 300 K has the following parameters:

$N_a = 3\times10^{24}$ m^{-3} , $N_d = 10^{21}$ m^{-3} , channel length L = 20μm, total channel thickness 2a = 4 μm, channel width Z = 100 μm, electron mobility $\mu_n = 0.1$ m^2 V-s.
$n_i = 1.5 \times10^{16}$ m^{-3}. Calculate:

- (i) the built-in-voltage. (3 marks)
- (ii) the pinch-off voltage. (3 marks)
- (iii) the drain conductance with gate voltage $V_G = 0$. (3 marks)
- (iv) the transconductance with drain voltage $V_D = 0.5$V and $V_G = -1$ V. (3 marks)
- (v) the transconductance in the linear region with $V_D = 0.5$ V. and $V_G = -1$ V. (3 marks)

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.
State the advantages of this technique over the Czochralski method of wafer preparation.
(10 marks)

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

(iii) 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)

Question Five.

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

(b) The dark resistance of a sample is 220 Ω. When illuminated with light the resistance decreases to 200 Ω. If a 2.5 mA current is passed through the sample the time constant of the voltage decay is 0.4 μs. Ignoring surface recombination, calculate

(i) the bulk life time. (4 marks)

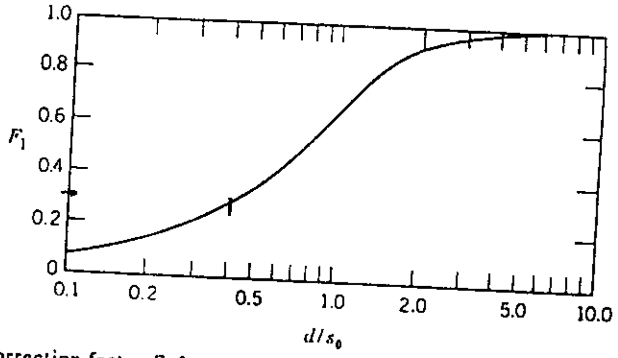
(ii) the sample voltage 0.2 μs after the removal of the light.
(4 marks)

(c) Four point probe method is used in a semiconductor wafer of diameter of 2.0 cm and thickness 0.25 m. 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. Calculate:

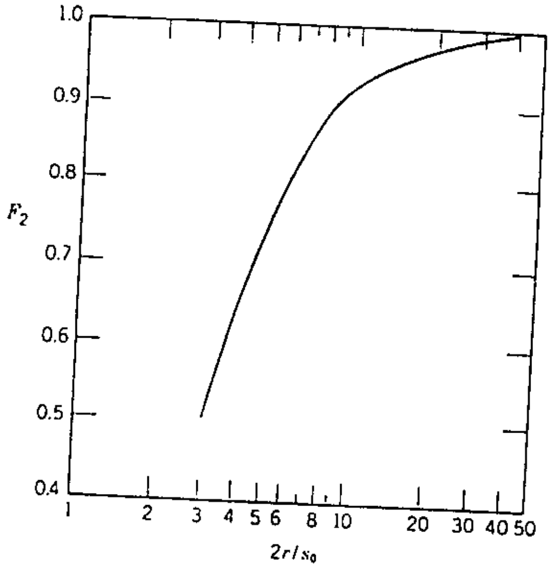
(i) the resistivity. (5 marks)
(ii) sheet resistance of the wafer. (2 marks)

[see appendix A for correction factors]

APPENDIX A.



Correction factor F_1 for a thin wafer placed on a nonconducting surface as a function of d/s_0.



Correction factor F_2 for probes centered on a circular wafer of finite diameter $2r$ as a function of the ratio $2r/s_0$.

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

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})	3900	1350	8500
Hole (cm^2 V^{-1} sec^{-1})	1900	480	400