UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

MAIN EXAMINATION 2011

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) Define **transit time ( $\tau_N$ )** and **life time ( $\tau_B$ )** 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 $\alpha_N = 0.95$. 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 $I_E + I_C = 0$)

## Question Two.

(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 $\alpha_o$ and $\omega_\alpha$ 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)

(b) (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* $V_{th}$ of 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)

**Question Five.**

(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 = $1.5 \times 10^{-4}$ 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 1

## Various definite integrals.

$$\int_0^\infty e^{-ax^2}\,dx = \frac{1}{2}\sqrt{\frac{\pi}{a}}$$

$$\int_0^\infty e^{-ax^2}\,x\,dx = \frac{1}{2a}$$

$$\int_0^\infty e^{-ax^2}x^3\,dx = \frac{1}{2a^2}$$

$$\int_0^\infty e^{-ax^2}\,x^2\,dx = \frac{1}{4}\sqrt{\frac{\pi}{a^3}}$$

$$\int_0^\infty e^{-ax^2}\,x^4\,dx = \frac{3}{8a^2}\left(\frac{\pi}{a}\right)^{1/2} .$$

$$\int_0^\infty e^{-ax^2}\,x^5\,dx = \frac{1}{a^3}$$

$$\int_0^\infty \frac{x^3\,dx}{e^x - 1} = \frac{\pi^4}{15}$$

$$\int_0^\infty x^{1/2}\,e^{-\lambda x}\,dx = \frac{\pi^{1/2}}{2\lambda^{3/2}}$$

$$\int_0^\infty \frac{x^4 e^x}{(e^x-1)^2}\,dx = \frac{4\pi^4}{15}$$

$$\int_0^\infty \frac{x^{1/2}}{e^x - 1}\,dx = \frac{2.61\pi^{1/2}}{2}$$

## Appendix 2

### Physical Constants.

| *Quantity* | *symbol* | *value* |
|---|---|---|
| Speed of light | c | 3.00 x $10^{8}$ $ms^{-1}$ |
| Plank's constant | h | 6.63 x $10^{-34}$ J.s |
| Boltzmann constant | k | 1.38 x $10^{-23}$ $JK^{-1}$ |
| Electronic charge | e | 1.61 x $10^{-19}$ C |
| Mass of electron | $m_e$ | 9.11 x $10^{-31}$ kg |
| Mass of proton | $m_p$ | 1.67 x $10^{-27\ \mathrm{kg}}$ |
| Gas constant | R | 8.31 J $mol^{-1}$ $K^{-1}$ |
| Avogadro's number | $N_A$ | 6.02 x $10^{23}$ |
| Bohr magneton | $\mu_B$ | 9.27 x $10^{-24}$ $JT^{-1}$ |
| Permeability of free space | $\mu_0$ | $4\pi$ x $10^{-7}$ $Hm^{-1}$ |
| Stefan constant | $\sigma$ | 5.67 x $10^{-8}$ $Wm^{-2}K^{-4}$ |
| Atmospheric pressure | | 1.01 x $10^{5}$ $Nm^{-2}$ |
| Mass of $_2^4$ He atom | | 6.65 x $10^{-27}$ kg |
| Mass of $_2^3$ He atom | | 5.11 x $10^{-27}$ kg |
| Volume of an ideal gas at STP | | 22.4 l $mol^{-1}$ |