GLASGOW COLLEGE UESTC

Electronic Devices (UESTC 3002)

Date:Dec.24th,2021
Time: 7:00-9:00pm

Attempt all PARTS. Total 100 marks

Use one answer sheet for each of the questions in this exam.
Show all work on the answer sheet.
For Multiple Choice Questions, use the dedicated answer sheet provided.

Make sure that your University of Glasgow and UESTC Student Identification Numbers are on all answer sheets.

An electronic calculator may be used provided that it does not allow text storage or display, or graphical display.

All graphs should be clearly labelled and sufficiently large so that all elements are easy to read.

The numbers in square brackets in the right-hand margin indicate the marks allotted to the part of the question against which the mark is shown. These marks are for guidance only.

FORMULAE SHEET IS PROVIDED AT THE END OF PAPER
Fundamental Constants and Useful Material Properties

$q = 1.6 \times 10^{-19}\, C$

$T = 300\, K$

$J = 1.38 \times 10^{-23} JK^{-1}$

$\epsilon_0 = 8.85 \times 10^{-12}\, Fm^{-1}$

$h = 6.62 \times 10^{-34}\, m^2 kg/s$

$Band\ Gap\ Si,\ E(Si) = 1.1\ eV$

$m_0 = 9.1 \times 10^{-31}\, kg$

Question 1: General Semiconductor Concepts [25 marks]

Answer the following questions:

a) Complete this sentence using the choices below: The diode ________. [1]
   i. Is the basic building block of all electronic devices.
   ii. Has similar characteristics to a simple switch
   iii. Is a 2-terminal device
   iv. All the above

b) Choose the correct answer: A current ratio of I_C/I_E is usually: [1]
   i. Less than unity
   ii. greater than unity
   iii. equal to unity
   iv. equal to zero

c) Complete this sentence: Diffused impurities with ________ valence electrons are called donor atoms. [1]
   i. 5
   ii. 3
   iii. 4
   iv. 0

d) Complete this sentence: In the atomic lattice, the ______ and _______ form the nucleus. [2]
   i. Electrons, neutrons
   ii. Protons, neutrons
   iii. Electrons, protons
   iv. All the above

e) What does a high resistance reading in the reversed bias region of a Bipolar Junction Transistor (BJT) indicate? [1]

f) What happens to a semiconductor's carrier mobility when the doping concentration is increased? [1]

g) At what angles to normal incidence is the output power of a solar cell greatest and lowest? [2]

h) A particular 1 cm^2 solar cell produces 40 W when placed under a sun concentration of X1000. What is the efficiency of this solar cell, assuming its Fill Factor is unity? [2]

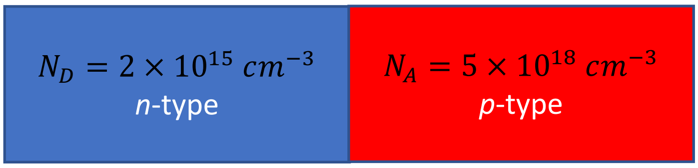
i) Calculate the gain of a transistor having $I_C = 10\ mA$ and $I_B = 100\ \mu A$. [2]

j) A transistor has a gain of 100 and a base current, I_B, of $50\ \mu A$. Calculate the emitter current, I_E . [2]

k) An n-type silicon of 1-micron length and cross-sectional area of 100 μm^2 has a voltage of 2 V applied across it. If $n_i = 1 \times 10^{10}\ cm^{-3}$, $N_d = 1 \times 10^{16}\ cm^{-3}$ and $\mu_n = 1500\ cm^2V^{-1}s^{-1}$, find the following:
   i) Electron drift velocity. [2]
   ii) Time it takes for an electron to cross the 1 μm length. [2]
   iii) Drift current density due to electrons. [2]
   iv) Drift current due to electrons. [2]

l) Find D_n assuming the n-type silicon is at room temperature and $\mu_n = 1500\ cm^2V^{-1}s^{-1}$ [2]

Question 2: PN-Junction Diode [25 marks]



a) Compare and contrast the energy band diagrams of this pn-junction diode in the forward and reverse bias regions, making sure to label all aspects of your schematic diagrams. [4]

b) Calculate the barrier potential of this diode, assuming $n_i = 10^{10} cm^{-3}$. [2]

c) Calculate the carrier concentration, p, on the n-side. [2]

d) Determine the depletion layer width when $\epsilon_r = 11.5$:
i) Reverse bias voltage of 4 V is applied. [2]
ii) Forward bias voltage of 0.5 V is applied. [2]

e) Explain the similarities and differences between a *pn*-junction diode and a single junction crystalline silicon solar cell. [4]

f) Draw a schematic diagram of a basic solar cell device, making sure to indicate the direction of incident light. [2]

g) A PV cell engineer fabricates a $100 \times 100\ mm^2$ solar cell that produces a 1.5 W output when illuminated with a 10 W light source. The designer measures a short circuit current of 3.5 A and an open circuit voltage of 0.61V. What is the efficiency and fill factor of this cell? [4]

h) How would you design a more efficient solar cell device? [3]

Question 3 – BJTs **[25 Marks]**

a) Discuss the typical characteristics of a Bipolar Junction Transistor (BJT). In your answer, make sure to explain the BJT's terminals with BJT symbols. Please also discuss which type of BJT is widely used and why? You may draw sketches to illustrate your answer. [9]

b) In a common base BJT connection, I_E = 1 mA, I_C = 0.95 mA. Calculate the value of I_B. [2]

c) Define cut-off, active and saturation regions in a BJT? [6]

d) If the collector current changes from 2 mA to 3 mA in a transistor when collector-emitter voltage is increased from 2 V to 10 V, what is the output resistance? [4]

e) What is τ_{FB} if W_B = 70 nm and D_B = 10 cm^2/s? Discuss the significance of your answer relative to the propagation of other electromagnetic waves. [4]

Question 4 – Field Effect Transistors [25 Marks]

a) Draw the transfer characteristic for n-channel depletion type MOSFET? [3]

b) Which JFET parameter(s) influence the size of the depletion region in the device. Please explain your answer [2]

c) Compare and contrast “Normally ON” and “Normally OFF” MOSFETs. Why are they termed this way? [5]

d) Define the amplification factor in a JFET? [5]

e) Compare the characteristics of JFET and MOSFET. [6]

f) Why is the FET called a “voltage operated device”? [2]

g) What do you understand by the term “pinch-off voltage”? [2]

EQUATION SHEET

$$E_a - E_b = h\nu_{ab} = \frac{mq^4}{8h^2\varepsilon^2}\left[\frac{1}{b^2} - \frac{1}{a^2}\right]$$

$$np = n_i^2$$

$$f_{FD}(E) = \frac{1}{1+\exp\left(\frac{E-E_F}{k_B T}\right)}$$

$$n = N_C \exp((E_F - E_C)/k_B T)$$

$$p = N_V \exp((E_V - E_F)/k_B T)$$

$$n_i = (N_c N_V)^{1/2}\exp\left(\frac{-E_g}{2k_b T}\right)$$

$$J_{n,drift} = qnv_d = qn\mu_n E$$

$$J_{p,drift} = qpv_d = qp\mu_p E$$

$$\mu_n = \frac{q\tau_n}{m_e} \quad \mu_p = \frac{q\tau_p}{m_h}$$

$$\mu_L = AT^{-3/2} \quad \mu_I = \frac{BT^{+3/2}}{N_i}$$

$$J_{n,diff} = qD_n\frac{dn}{dx} \quad J_{p,diff} = -qD_p\frac{dp}{dx}$$

$$\psi_0 = \frac{E_F^n - E_F^p}{q} = \frac{k_B T}{q}\ln\left(\frac{N_D N_A}{n_i^2}\right)$$

$$w = x_p + x_n = \left(\frac{2\varepsilon_0\varepsilon_S(\psi_0 + V)(N_D + N_A)}{qN_A N_D}\right)^{1/2}$$

$$p_n(x) = (p_n(x_n) - p_{n0})\exp\left(-\frac{(x - x_n)}{L_p}\right) + p_{n0}$$

$$n_p(x) = (n_p(-x_p) - n_{p0})\exp\left(\frac{(x + x_p)}{L_n}\right) + n_{p0}$$

$$n_p(-x_p) = n_{p0}\exp\left(\frac{V_F}{\phi_T}\right)$$

$$p_n(x_n) = p_{n0}\exp\left(\frac{V_F}{\phi_T}\right)$$

$$I = I_0\left(\exp\left(\frac{V_F}{\phi_T}\right) - 1\right)$$

$$I_0 = Aq\left(\frac{D_p p_{n_0}}{L_P} + \frac{D_n n_{p_0}}{L_n}\right) = Aqn_i^2\left(\frac{D_p}{L_P N_D} + \frac{D_n}{L_n N_A}\right)$$

$$\frac{D_e}{\mu_e} = \frac{kT}{e} \quad \text{and} \quad \frac{D_h}{\mu_h} = \frac{kT}{e}$$

$$L_n = \sqrt{D_n\tau_n}$$

$$L_p = \sqrt{D_p\tau_p}$$

$$I = I_0\exp\left(\frac{V_F}{n\phi_T}\right)$$

$$I_o = AA^* T^2\exp(-(q\phi_B)/kT)$$

$$Q_{Bm} = -qN_a x_{dm} \quad x_{dm} = \sqrt{\frac{2\varepsilon_0\varepsilon_s 2\phi_f}{qN_a}}$$

$$V_T = -\frac{Q_{Bm}}{C_o} + 2\phi_f$$

$$Q_I = -C_o(V_G - V_T)$$

$$V_{FB} = -\frac{Q_o}{C_o} + \phi_{ms}$$

$$V_T = -\frac{Q_{Bm}}{C_o} + 2\psi_B + V_{FB}$$

$$I_D = C_o\mu_{ns}\frac{W}{L}\left[(V_G - V_T)V_D - \frac{V_D^2}{2}\right]$$

$$I_{DS} = \mu_{ns}C_o\frac{W}{2L}(V_G - V_T)^2$$

$$f_T = \frac{\mu_{ns}V_D}{2\pi L^2} \quad f_T = \frac{v_s}{2\pi L}$$

$$I_{DS} = -WQ_I v_s = WC_o v_s(V_G - V_T)$$

$$D = D_0\exp\left(-\frac{E_A}{kT}\right)$$

$$F = -D\frac{\partial C}{\partial x}$$

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$$

$$C(x,t) = C_s\,\mathrm{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$C(x,t) = \frac{Q}{\sqrt{\pi Dt}}\exp\left(-\frac{x^2}{4Dt}\right)$$

$$C(x) = \frac{Q}{\sqrt{2\pi}\Delta R_p}\exp\left(-\frac{(x - R_p)^2}{2\Delta R_p}\right)$$

$$w_{ox}^2 + Aw_{ox} = B(t + \tau_i)$$

$$\tau_i = \frac{w_{ox\,i}^2}{B} + \frac{w_{ox\,i}}{B/A}$$

$$w_{ox} = \frac{A}{2}\left\{\left(1 + \frac{t + \tau_i}{A^2/4B}\right)^{1/2} - 1\right\}$$

$$w_{ox} = \frac{B}{A}(t + \tau_i) \quad w_{ox} = \sqrt{Bt}$$

$$\tau_t = \frac{W_B'^2}{2D_B}$$

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

$$I_{DS} = K(V_{GS} - V_{th})^2(1 + \lambda V_{DS})$$
for $V_{GS} > V_T$, $V_{DS} > V_{GS} - V_T$

$$A_V = \frac{v_{ds}}{v_{gs}} = -\frac{R_D\left(g_m v_{gs}\right)}{v_{gs}} = -g_m R_D$$

$$K = \frac{Z\mu_e \epsilon}{2Lt_{ox}}$$

$$x_p = \sqrt{\frac{2\epsilon_o \epsilon_r V_{bi} N_d}{qN_a(N_d + N_a)}}$$

$$N_v = 2\left(\frac{2\pi m_h^* kT}{h^2}\right)^{3/2}$$

$$x_n = \sqrt{\frac{2\epsilon_o \epsilon_r V_{bi} N_a}{qN_d(N_d + N_a)}}$$

$$N_c = 2\left(\frac{2\pi m_e^* kT}{h^2}\right)^{3/2}$$

$$W = \sqrt{\frac{2\epsilon_r \epsilon_o V_{bi}(N_a + N_d)}{qN_d N_a}}$$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$I_{DS} = \frac{\mu C_{ox} Z}{L}\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2}\right](1 + \lambda V_{DS})$$
for $V_{GS} > V_T$, $V_{DS} \leq V_{GS} - V_T$