BITS, PILANI – DUBAI
FIRST SEMESTER 2009 – 2010
COMPREHENSIVE EXAMINATION
YEAR III EEE

Course Code: EEE C381 | Date: 27.12.09
Course Title: Electronic Devices and Integrated Circuits | Max Marks: 80
Duration: 3 Hours | Weightage: 40%

Instructions: (if any): Answer ALL Questions. The question paper has two sections, A and B. Answer section A in the BLUE coloured answer booklet and section B in the GREEN answer booklet. All symbols have their usual significance. Assume appropriate values of any constants not provided.

SECTION – A (Answer this section in the **BLUE** answer booklet)

1) Explain how the bandgap of a semiconductor can be determined from a plot of intrinsic carrier concentration as a function of temperature. For an intrinsic semiconductor, the electron concentrations at 300 K and 400 K are found to be 10^{10} cm^{-3} and 10^{13} cm^{-3} respectively. Determine the bandgap of the semiconductor.

(8 marks)

2) A silicon sample is doped with 10^{16} cm^{-3} boron atoms along with a certain concentration N_d cm^{-3} of phosphorus atoms. The Fermi level for the semiconductor is located at 0.3 eV above the intrinsic level E_i at 300 K. Assume n_i at 300 K to be 10^{10} cm^{-3}. Determine N_d.

If N_d in the above problem is doubled, by how much will the Fermi level shift? Where will the Fermi level be now located, closer to the conduction band or valence band?

(8 marks)

3) Using the Ebers - Moll coupled diode model, draw the equivalent circuit of an npn transistor. Indicate the terminal currents in the model and explain the significance of the diodes and dependent current sources used. Hence write down the expressions for the terminal currents in terms of the model parameters.

(8 marks)

4) Light is incident on a p-n junction optoelectronic device at 300 K, with an optical generation rate g_{op} = 10^{15} $cm^{-3}.s^{-1}$. There is also a thermal generation rate g_{th} $cm^{-3}.s^{-1}$. Assume a symmetrical junction, with $p_p = n_n = 10^{18}$ cm^{-3}. The minority carrier lifetime is 10^{-7} s. The intrinsic carrier concentration n_i for the semiconductor at 300 K is 10^{10} cm^{-3}. Determine the open circuit voltage V_{oc} for the device.

(8 marks)

5) Explain with the help of band diagrams, the process of tunneling in a p^+-n^+ diode under both forward and reverse bias conditions. Hence draw the I – V characteristics and indicate the negative resistance region in the characteristics. What does the negative resistance signify?

(8 marks)

P.T.O

SECTION – B (Answer this section in the **GREEN** answer booklet)

1) Calculate the surface potential ϕ_s at the onset of strong inversion for a MOS structure at 100° C corresponding to a substrate doping of 10^{16} cm^{-3}. The semiconductor is silicon. Assume $n_i = 2x10^{12}$ cm^{-3} at 373 K.

(5 marks)

2) Plot $I_{D(sat)}$ vs V_D at 300K for a Si n channel JFET with Na = 10^{18} cm^{-3}, 2a= 2 μm, $N_d = 10^{16}$ cm^{-3}, Z=50 μm, and L=5 μm and allow V_g to take on values 0,-1,-2,-3,-4,and -5 V. Given μ_n = 1000 cm^3 /Vs. Find the contact potential V_o across the p-n junction formed, V_P, and V_T.

(6 marks)

3) A Si p-n junction has $p_p = 10^{17}$ cm^{-3} and $n_n = 10^{15}$ cm^{-3}, μ_p= 450 and μ_n=700 cm^2 /V-s, $\tau_p = 10^{-5}$ s and A=10^{-4} cm^2. Draw the band diagram qualitatively under forward and reverse bias showing quasi Fermi levels.

(6 marks)

4) Find the forward current at a forward bias of 0.5 V and the current at a reverse bias of 0.5 V for the above problem.

(4 marks)

5) A Si bar of 0.1 cm long and 100 μm^2 in cross sectional area is doped with 10^{17} cm^{-3} of Sb. Find the current at 300 K with 10V applied across the bar.

(5 marks)

6) i) A Si p^+-n junction with $N_D = 8\times10^{16}$ cm^{-3} and A= 10^{-3} cm^2 has τ_p=1 μs and D_p=10 cm^2/s. Find I for a forward voltage V_f = 0.5 V.

ii) Calculate the total depletion capacitance at -4 V.

(6 marks)

7) An n^+ polysilicon gate, p-channel MOSFET is made on an n-type substrate with $N_d = 5\times10^{16}$ cm^{-3}. The SiO_2 thickness is 10 nm in the gate region and the effective interface charge Q_i is 2×10^{11}q C/cm^2. Find W_m, flatband voltage V_{FB}, and threshold voltage V_T and sketch the C-V curve. Given work function difference ϕ_{ms} = -0.2 V

(8 marks)

END OF PAPER

BITS, PILANI – DUBAI
DUBAI INTERNATIONAL ACADEMIC CITY

EEE C381 – ELECTRONIC DEVICES AND INTEGRATED CIRCUITS YEAR III

Test II (Open Book) Date: 10 Dec 2009 Max marks: 40 Weightage: 20%

Answer ALL questions **Time allowed: 50 minutes**

Note: All symbols have their usual significance. Assume appropriate value for any constant not provided.

Q1 A Si solar cell has an I-V characteristics as shown in Figure 1. A steady light of intensity 800 $W.m^{-2}$ is incident on the p-n junction.

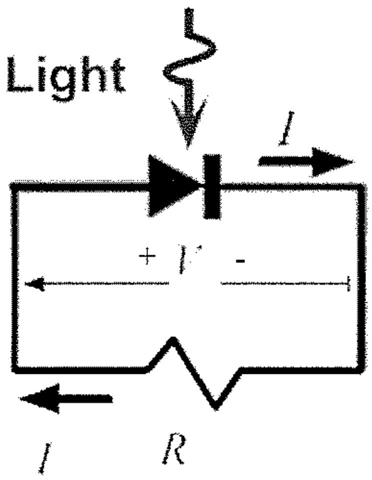

Figure 2

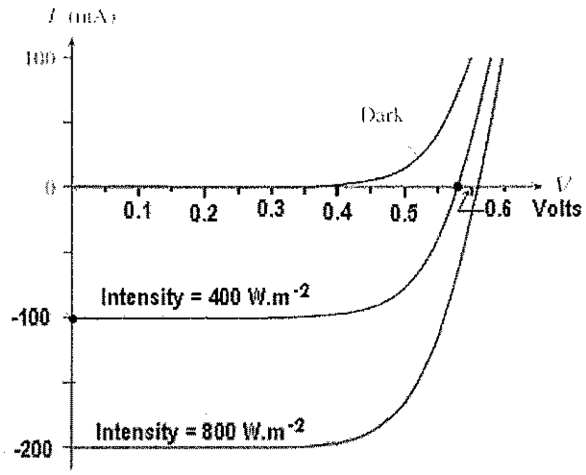

Figure 1

(a). In Figure 2, the solar cell drives a load R = 2·5 ohms. Indicate on this figure (provided as a separate sheet) the load line for the circuit. Hence determine the operating point. Also indicate the open circuit voltage and the short circuit current and determine the Fill Factor.

(6 marks)

(b) How much power does the solar cell deliver to the load? If the efficiency of the solar cell in this circuit is 10%, what is the junction area of the solar cell?

(4 marks)

(c) By connecting three solar cells similar to the one discussed in part (b) in series, a certain load is found to draw 100 mA current. At what voltage does the load operate? Determine the load resistance and the power conversion efficiency.

(4 marks)

Q2 (a) Sketch the energy band diagram for an ideal MOS structure using n-Si for the following two cases: (i) $V_G > 0$ and (ii) $V_G \ll 0$. Indicate all energy levels in the diagram. If the semiconductor electron affinity is 4.05 eV, and its bandgap is 1.12 eV, how far is the Fermi energy from the intrinsic energy for the semiconductor when the applied bias is zero? Assume that the metal work function is 4.4 eV.

(6 marks)

Q3. An n-channel Si JFET has p^+ regions doped with 5×10^{18} acceptors /cm^3 and an n-channel with 8×10^{15} donors cm^{-3}. Assume T = 300 K and $n_i = 10^{10}$ cm^{-3}. If the channel half width a is 1.5 μm, compare the pinch off voltage V_P for the JFET with the contact potential V_o for the p-n junction. The effect of the contact potential V_o is to provide an effective gate potential $V_G' = (V_G - V_o)$ instead of V_G. Determine the minimum drain voltage V_D needed to provide a saturation drain current for an applied gate voltage $V_G = -2$ V. The source terminal is grounded. Calculate the conductance G_o for the channel and hence determine the saturation drain current I_D(sat).
Assume $\mu_n = 1000$ cm^2.V^{-1}.s^{-1} and (Z/L) = 10 for the channel.

(10 marks)

Q4. (a) Draw the energy band diagram for an n-p-n transistor in active mode of operation. Indicate in the diagram the conduction and valence band edges, Fermi levels, depletion regions, contact potential and the applied bias voltages V_{EB} and V_{CB}.

(b) Consider a p-n-p transistor operated at 300 K with a base doping of $N_B = 10^{16}$ cm^{-3}. Assume $n_i = 10^{10}$ cm^{-3}. The forward bias emitter – base voltage is 0.6 V.

(i) Determine the excess hole concentration injected into the base from the emitter.

(ii) If the reverse biased collector – base voltage is very large, what will be the excess hole concentration at the edge of the collector- base depletion region?

(iii) Why should the base width be very narrow for effective transistor action?

(10 marks)

END OF PAPER

BITS, PILANI – DUBAI
DUBAI INTERNATIONAL ACADEMIC CITY

YEAR III EEE C381 – ELECTRONIC DEVICES & INTEGRATED CIRCUITS

Test 1 **Date: 18 Oct 2009** **Max marks: 50** **Weightage: 25%**

Answer ALL questions **Time allowed: 50 minutes**

Q1
Write down an expression for the conductivity of a semiconductor in terms of its carrier concentrations, carrier mobilities and carrier charges. Differentiate this expression to determine the condition for which the conductivity is lowest and hence show that the minimum conductivity is given by

$$\sigma_{\min} = 2n_i q\sqrt{\mu_n \mu_p}$$

where n_i is the intrinsic carrier concentration for the semiconductor at a given temperature. Hence show that this occurs when the semiconductor is p-type. Assume that the electron mobility μ_n is greater than the hole mobility μ_p and that the mobility is independent of carrier concentration.

[14 marks]

Q2.
Silicon is doped with only donor atoms and held at room temperature (T=300 K). The donor doping density is comparable to the intrinsic carrier concentration, n_i . If, $n_i = 1.5\text{x}10^{10}$ cm^{-3} and the thermal equilibrium electron concentration, n_o is $7\text{x}10^{10}$ cm^{-3}, determine the hole concentration p_o in the semiconductor. Hence show that the donor density N_d is $6.68\text{x}10^{10}$ cm^{-3}.

How far is the Fermi energy E_F above the intrinsic Fermi energy E_i in the semiconductor?

[12 marks]

Q3
For the semiconductor described in **Q2**, the donor doping density is increased to a level which is 100 times its present value. Use appropriate assumptions to estimate the new equilibrium values of n_o and p_o. Would you expect the Fermi level to shift as a result of this increased doping? If so, by how much?

[12 marks]

Q4.
Draw the energy band diagram of a *p-n* junction in thermal equilibrium. In the band diagram, indicate the following:

i)conduction and valence band edges in the *p-* and *n-* side of the junction,
ii) the Fermi Energy,
iii) the built-in potential, V_o, and
iv) the region where there is a presence of immobile space charge on either side of the metallurgical junction.

If the *p-n* junction is heated to a high temperature, how would the band diagram look like? What will be V_o? Explain.

[12 marks]

BITS, PILANI – DUBAI

FIRST SEMESTER 2009 – 2010

QUIZ - 1

Course Code: EEE C381 | YEAR III EEE

Course Title: Electronic Devices and Integrated Circuits

Duration : 20 minutes

Date: 30.09.09

Max Marks: 32

Weightage: 8%

Name: . **ID No:** . **Sec : EEE1 / EEE2.**

Instructions: (if any): Answer ALL Questions. Please use both sides of the paper for your answers.

Q1. Define Fermi-Dirac distribution function. In a certain semiconductor, the probability that a certain energy state E is occupied by a hole is 0.1% at 300 K. What is the probability for the same energy state to be occupied by a hole at 600 K ? (10 marks)

PTO

Q2. Given that $n_o = N_c e^{-(E_c - E_F)/k_B T}$ and $p_o = N_v e^{-(E_F - E_v)/k_B T}$ where N_c, N_v refer to effective density of states at the conduction and valence band edges respectively and n_o, p_o refer to thermal equilibrium electron and hole concentrations respectively, show that the bandgap E_g of the semiconductor can be expressed as $E_g = k_B T \ln\left(\frac{N_c N_v}{n_i^2}\right)$. Other symbols have their usual meanings

(6 marks)

PTO

Q3. Determine the conductivity (σ) of an intrinsic semiconductor at 300 K. Given that n_i = $2.5x10^{13}$ cm^{-3} at 300 K, μ_n = 3800 $cm^2.V^{-1}.s^{-1}$ μ_p = 1800 $cm^2.V^{-1}.s^{-1}$. Assume suitable value for electronic charge. (8 marks)

PTO

Q4. Write down an expression for electrical conductivity of n-type semiconductor in terms of its carrier concentration, carrier mobility and electronic charge. If the temperature (T) of the semiconductor is increased gradually from a very low value to a very high value, qualitatively explain and draw appropriate graphs to show the variation of carrier concentration and mobility with (1/T). Hence plot the variation of electrical conductivity with (1/T). Indicate room temperature (T = 300 K) in the plot. (8 marks)

BITS, PILANI – DUBAI
FIRST SEMESTER 2009 – 2010
QUIZ - 2

Course Code: EEE C381 **YEAR** III EEE Date: 18.11.09
Course Title: Electronic Devices and Integrated Circuits Max Marks: 28
Duration : 25 minutes Weightage: 7%

Name: . **ID No:** . **Sec : EEE1 / EEE2.**

Instructions: (if any): Answer ALL Questions. Please use both sides of the paper for your answers.

Q1. Figure 1 describes the output characteristics for an n-channel JFET with $N_d = 10^{16}$ cm^{-3}

The pinch off point for each characteristic is also indicated. Assume $V_{GS} = -2$ V

(a) Determine the pinch-off voltage V_P for the JFET (3 marks)

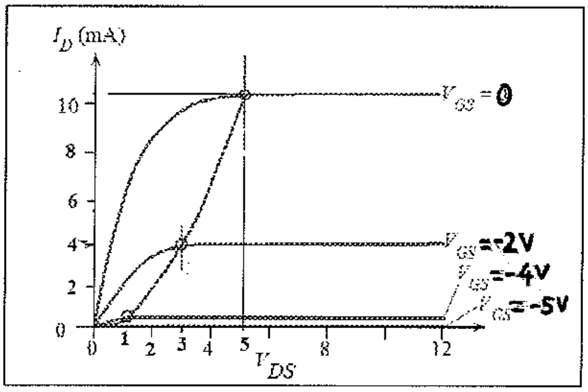

Figure 1

(b) The drain current for the JFET is given by the equation

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

where the symbols have their usual significance. Using the above equation, make appropriate substitutions to express the saturation drain current in terms of G_o and V_P. (4 marks)

PTO

(c) Use Figure 1 and the results obtained in (a) and (b) above to determine the channel conductance G_o (3 marks)

(d) From the knowledge of the pinch-off voltage, determine the channel thickness *2a* Permittivity of the semiconductor is $\varepsilon = 11.7 \times 8.854 \times 10^{-14}$ F/cm and $q = 1.6 \times 10^{-19}$ coul. (2 marks)

(e) If the conductance G_o is assumed to be due to a channel of thickness 2a, length L and width Z, determine the ratio (Z/L) of the channel. Assume $\mu_n = 1500$ $cm^2.V^{-1}s^{-1}$. (3 marks)

Q2a. Draw the energy band diagram of a MOS structure with a p-type semiconductor where the metal gate end is held at a small positive voltage and the semiconductor end is grounded. Indicate depletion region, conductance and valence band edges, and the Fermi levels. Explain any bending in the bands (8 marks)

Q2b. What happens when the metal gate voltage is progressively increased? Define the condition that indicates the onset of strong inversion. Draw the band diagram that indicates this condition (5 marks)