BITS, PILANI – DUBAI
DUBAI INTERNATIONAL ACADEMIC CITY
SEMESTER I 2010-2011

CLASS: EEE III Year **Date: 28 Dec 2010**

EEE C381 ELECTRONIC DEVICES AND INTEGRATED CIRCUITS

Max marks: 80 Weightage: 40% **COMPREHENSIVE EXAMINATION** Time allowed: 3 hours

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Note: Answer ALL questions. All symbols have their usual significance unless otherwise stated

Q1 (a) Define Fermi-Dirac probability function $f(E)$. A semiconductor is in thermal equilibrium, at an unknown temperature T (in K). Write down an expression for the probability P_e for an electron to occupy a state at the conduction band edge, E_c. Also write down an expression for the probability P_h for a hole to occupy a state at the valence band edge, E_v.

(b) For the above mentioned semiconductor, if the Fermi level E_F is 0.06 eV above the mid band level (E_{mid}) and $T = 300$ K, by what factor is P_e greater than P_h ? Assume that E_F is far away from the band edges.

(10 marks)

Q2. In a doped Si, the probability of a hole occupying a state at an energy kT below the valence band edge E_v is 3.4×10^{-14}. Is the semiconductor n-type or p-type? Explain. Determine the position of the Fermi level in the material with reference to the conduction band edge E_c. Assume room temperature.

(5 marks)

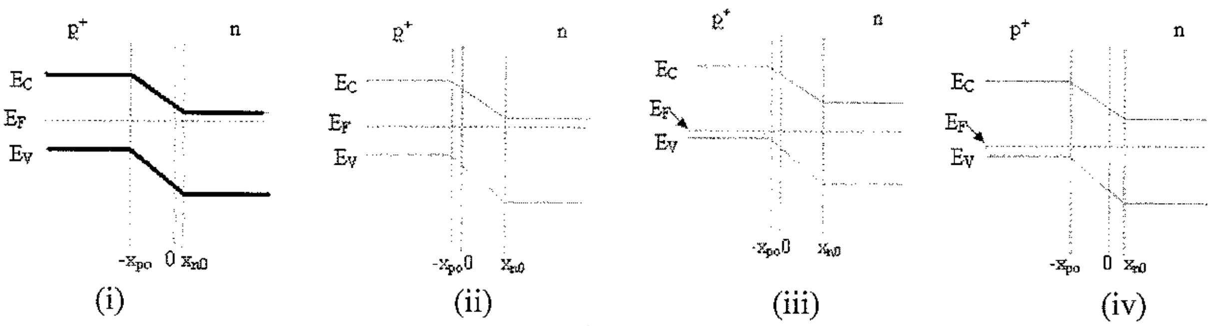
Q3. A piece of p-type doped silicon at 300 K has an equilibrium electron concentration of 2×10^5 cm^{-3}. By shining light, 10^{13} cm^{-3} excess carriers are injected. Does this correspond to high level injection or low level injection? Determine the location of the quasi Fermi level for holes, E_{Fpq} with respect to E_F.

(6 marks)

Q4 A Si p$^+$-n junction is formed with $N_A = 10^{18}$ cm^{-3} for the p-side and $N_D = 10^{15}$ cm^{-3} for the n-side. The junction is in thermal equilibrium at T = 350K.

(a) Determine the contact potential V_o across the junction.

(b) Which one of the options shown in Figure 1 below more closely represents the energy band diagram for the p$^+$-n junction?



(i) (ii) (iii) (iv)

Figure 1

(c) Calculate the ratio of x_{no} to $|x_{po}|$ for the p^+-n junction.

(12 marks)

Q5 Starting from a bare wafer (Figure 2) it is desired to make a pattern of silicon dioxide (Figure 3). Illustrate how a photolithography process can be used to accomplish this in nine steps, with a **positive** photoresist. If a negative photoresist is used, what mask pattern is required?

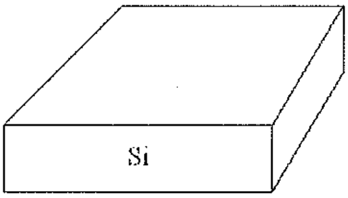


Figure 2

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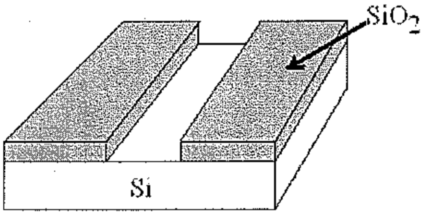

Figure 3

(7 marks)

Q6. Draw the energy band diagram of a p^+-n-p transistor biased in the cut off mode of operation. In the diagram, mark the Fermi levels, conduction and valence band edges, applied bias voltages and the energy barriers at the two interfaces for the transistor.

(5 marks)

Q7. Explain briefly the operating principle of a solar cell. Define the following terms: (i) fill factor, (ii) open circuit voltage, and (iii) short circuit current. Indicate the same in the I-V characteristic of a solar cell. Under what conditions a solar cell would be supplying maximum power to a load?

(10 marks)

Q8 Two identical solar cells are connected in series and uniformly illuminated by light of intensity 800 $W.m^{-2}$. A load R of 10 ohms is connected as shown in Figure 4. The I-V characteristics for each solar cell is shown in Figure 5.

(i) Draw the load line and the relevant I-V characteristic for the solar cell.

(ii) Estimate the **total** power delivered by the solar cells to the load.

(iii) If the active area of each solar cell measures 2 cm x 2 cm determine the operating efficiency,

(iv) If it is desired to maximize the power delivered to the load, estimate the typical load resistance that is to be used.

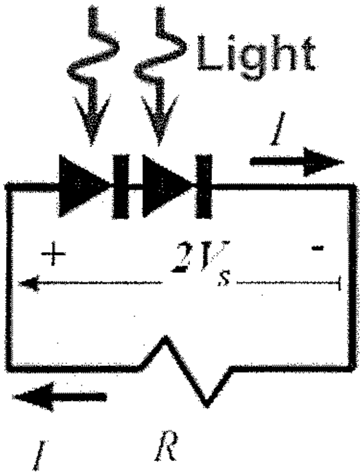

Figure 4

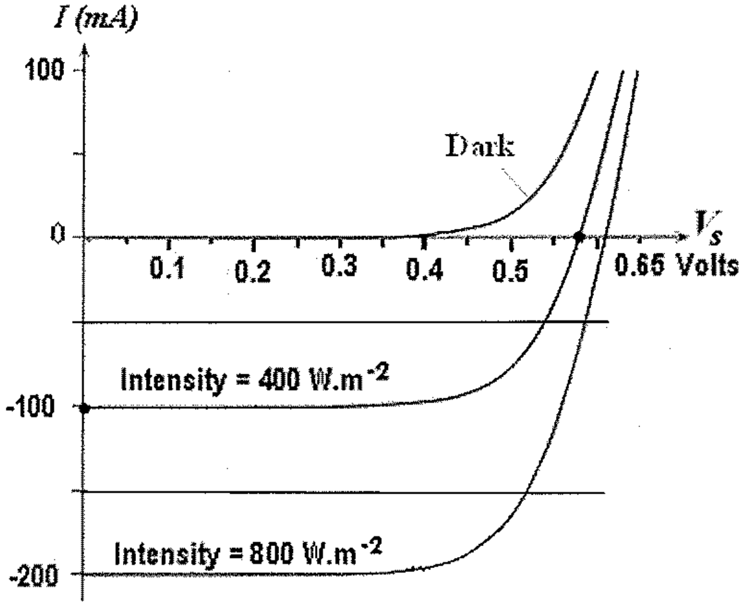

Figure 5

(15 marks)

Q9 Draw the energy band diagram of a tunnel diode at thermal equilibrium. Hence explain the operation of the tunnel diode under forward and reverse bias conditions. Consider the conduction band edge on the n-side as a reference ($E_{cn} = 0$ eV). In a certain tunnel diode, it is observed that the equilibrium Fermi Level is located at 0.1 eV and the valence band edge on the p-side is located at 0.15 eV ($E_{Vp} = 0.15$ eV). Calculate the amount of forward bias needed to produce (a) maximum tunneling current, and (b) minimum tunneling current.

(10 marks)

END OF PAPER

TABLE OF SELECTED CONSTANTS

Parameter	Symbol	Value	Units
Electronic Charge	q	1.6×10^{-19}	C
Boltzmann's constant	k or k_B	1.38×10^{-23}	J/K
Permittivity of free space	ε_o	8.85×10^{-14}	F/cm
Dielectric constant of Si (ε_r)	ε_{Si}	11.7	-
Intrinsic carrier concentration in Si	n_i	1×10^{10} at 300 K 2.75×10^{11} at 350 K	cm^{-3}
Bandgap of Si	E_g	1.12	eV

BITS PILANI DUBAI CAMPUS
EEE C381 –ELECTRONIC DEVICES AND INTEGRATED CIRCUITS- Test 2

Sem1, 2010- 2011 OPEN BOOK Time Allowed: 50 mins
Total Marks : 40 Weightage: 20%

INSTRUCTIONS: This paper contains **FIVE (5)** questions. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings. Make appropriate assumptions wherever applicable.

Q1. A Si solar cell of area 2 cm × 2 cm is connected to drive a load *R* as in Figure 1. It has the I-V characteristics in Figure 2

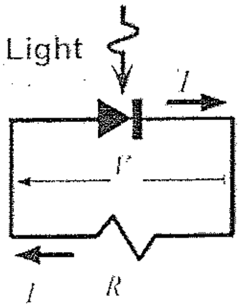

Figure 1

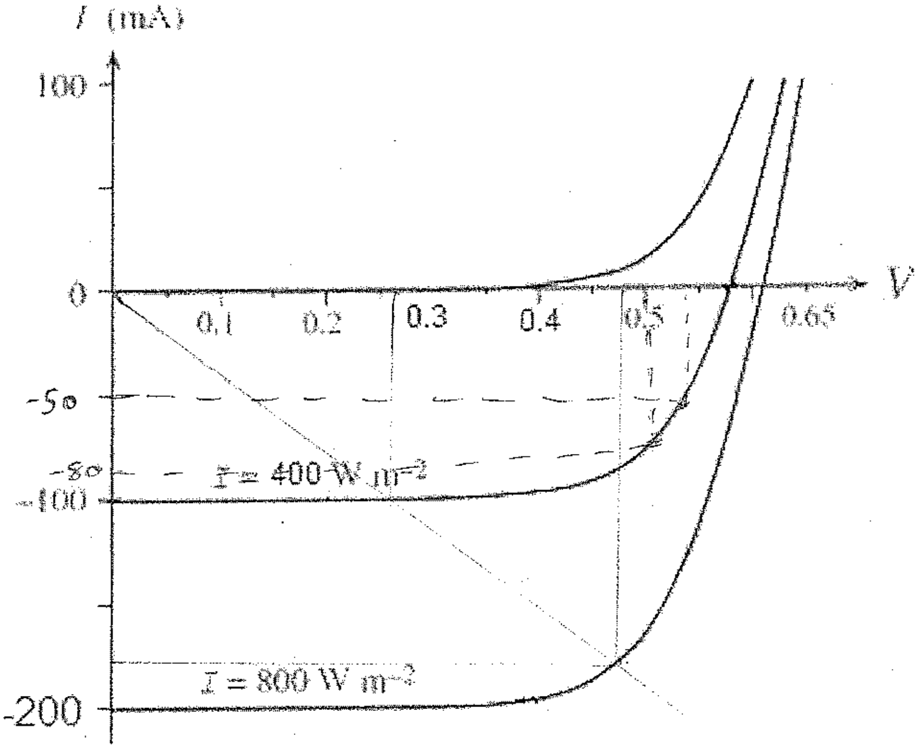

Figure 2

(a) Determine the open circuit voltage and short circuit current for the solar cell under light intensity of (i) 800 W.m^{-2}, and (ii) 600 W.m^{-2}. (2 marks)

PTO

(b) With a light of intensity 800 W.m^{-2} incident on the solar cell, what should be the load resistance R such that maximum electrical power is delivered to it? What is the efficiency of the solar cell under this condition? Determine the fill factor (6 marks)

(c) Under the conditions mentioned in part (b) above, if the intensity suddenly drops to 400 W.m^{-2}. What is the power delivered to the load now? Determine the efficiency of the solar cell under this condition. By how much should the load resistance be changed so that the efficiency is maximum now? (6 marks)

(d) Consider using a panel of 4 such solar cells connected in series to drive a small motor. When the solar panel is uniformly exposed to a light intensity of 400 W m^{-2}, the motor draws a current of 50 mA. Determine the operating voltage for the motor and hence the power drawn by the motor. What is the efficiency of the solar panel under this condition? (6 marks)

Q2. Draw the energy band diagram for a typical p^{+}-n-p transistor under active mode of operation. Indicate all energy levels and correlate the Fermi levels in the emitter, base and collector regions to the applied biases. (5 marks)

Q3. Starting from a generalized set of Ebers Moll equations, make suitable approximations to represent the total emitter and collector currents of a p-n-p transistor under (i) saturation and (ii) cut off mode of operation. (5 marks)

Q4. For an ideal MOS made of Al metal, SiO_2 , and p-type Si for which $N_a = 10^{17}$ cm^{-3}, calculate the maximum width of the surface depletion region. Assume T = 300 K. (5 marks)

Q5. If the oxide thickness for the MOS in Question 4 is 5 nm, determine the maximum and minimum capacitances for the MOS structure (5 marks)

Given: Bandgap of Si = 1.12 eV . Intrinsic carrier concentration n_i for Si at 300 K = 10^{10} cm^{-3}.
ε_r of Si = 11.8. ε_r of SiO_2= 3.9 Permittivity of free space = 8.85 x 10^{-14} Farad / cm.
Electronic Charge = 1.6 x 10^{-19} Coul. Boltzmann's constant = 1.38 x 10^{-23} J/K

BITS PILANI DUBAI CAMPUS
EEE C381 –ELECTRONIC DEVICES AND INTEGRATED CIRCUITS- Test 1

Sem1, 2010- 2011 CLOSED BOOK Time Allowed: 50 mins
Total Marks : 50 Weightage: 25%

INSTRUCTIONS: This paper contains **FIVE (5)** questions. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings. Make appropriate assumptions wherever applicable.

Q1. A semiconductor sample is in thermal equilibrium at 300 K. The bandgap energy is 1.12 eV and the intrinsic carrier concentration n_i is 10^{10} cm^{-3}. The sample is doped with donor impurities such that E_F is 0.026 eV above the intrinsic Fermi Energy level E_i.

(i) Calculate the thermal equilibrium electron and hole concentrations, n_0 and p_0 respectively.
(ii) Determine the donor impurity concentration N_D in the semiconductor. Is it justified to assume N_D to be the same as n_0?
(iii) If the donor impurity concentration is doubled, how much closer would the Fermi level be to the bottom of the conduction band?

(4 + 4 + 5 =13 marks)

Q2. A cylindrical piece of p-type silicon sample has a radius which is ten times its length. The doping concentration in the sample is $1x10^{18}$ cm^{-3}. The sample is held at 300 K.

(a) If the hole mobility at 300 K is 150 cm^2/V-s, calculate the conductivity of the sample.
(b) A dc voltage of 1.5 Volts applied across its flat ends results in a current of 150 mA. Determine the sample dimensions.
(c) If the temperature is slowly reduced, explain how the conductivity of the sample would change.

(4 + 4 + 4 = 12 marks)

Q3. A Si p-n junction has donor and acceptor doping concentrations N_D and N_A of 10^{16} cm^{-3} and 10^{18} cm^{-3} respectively. The p-n junction is held at 300 K. Assume that $n_i = 10^{10}$ cm^{-3} and ε_r for Si = 11.8. Calculate under thermal equilibrium conditions:

(a) the Fermi energy level relative to the intrinsic energy levels in both the n- and p-side of the junction. Hence draw the equilibrium energy band diagram.
(b) the contact potential V_o, using the data on the doping densities. Compare this result with that obtained through part (a) above.
(c) the peak electric field E_o and the location of the peak electric field.

(5 + 4 + 4 =13marks)

Q4. If P_e and P_h represent electron and hole probability for occupying an energy state E respectively, and $P_e = 10P_h$, How far is the energy state E with respect to E_F?

(5 marks)

Q5. A certain semiconductor has its electron mobility twice that of hole mobility. The semiconductor is initially undoped and the intrinsic carrier concentration $n_i = 10^{10}$ cm^{-3}. The semiconductor is now doped with a certain type of impurity. The conductivity of the doped semiconductor is found to be the same as the undoped conductivity. Determine the thermal equilibrium electron and hole concentrations (n_0 and p_0) in the doped semiconductor. What type of impurity has the semiconductor been doped with, donor or acceptor? Explain.

(7 marks)

NAME: **ID NO.:** **SET A**

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YEAR III EEE C381 – ELECTRONIC DEVICES & INTEGRATED CIRCUITS

Quiz 2 **Date: 09 Dec 2010** **Max marks: 14** **Weightage: 7%**

Answer ALL questions CLOSED BOOK **Time allowed: 20 minutes**

Q1. In a MOS structure, the semiconductor is n-type with donor doping density of $N_d = 1\text{x}10^{16}$ cm^{-3}. The oxide is 10 nm thick. A voltage V is applied at the metal surface. Assume T = 300 K.

(a) Draw the energy band diagram for the semiconductor when V< 0, Show the bending of the bands near the oxide-semiconductor interface. Identify the cases where the MOS structure operates in a depletion mode and inversion mode.

(b) What happens if V << 0 ? [Answer in one line]

(c) If E_i represents intrinsic Fermi energy level, and ϕ represents semiconductor potential defined by $q\phi = [E_{i,(bulk)} - E_i]$, determine the value of ϕ (in volts) (i) deep inside the semiconductor (ii) at the semiconductor – oxide interface, at the onset of strong inversion.

Assume: $n_i = 10^{10}$ cm^{-3} for Si at 300 K, ε_r for Si = 11.7, ε_r for SiO$_2$ = 3.9, $\varepsilon_o = 8.85 \times 10^{-14}$ Farad / cm

(d) Determine the total MOS capacitance at the onset of strong inversion

(10 marks)

Q2. A n^+-p-n transistor is biased in the active mode.

(i) Draw a schematic representation of the transistor indicating the B-E and C-B biases, depletion regions at the two junctions, components of the emitter current I_E , collector current I_C and base current I_B.

(ii) Define emitter injection efficiency γ and base transport factor B for the above structure.

(4 marks)

Assume: $n_i = 10^{10}$ cm^{-3} for Si at 300 K, ε_r for Si = 11.7, ε_r for SiO_2 = 3.9, $\varepsilon_o = 8.85 \times 10^{-14}$ Farad / cm

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YEAR III EEE C381 – ELECTRONIC DEVICES & INTEGRATED CIRCUITS

Quiz 1 **Date: 24 Nov 2010** **Max marks: 16** **Weightage: 8%**

Answer ALL questions CLOSED BOOK **Time allowed: 20 minutes**

Q1. An abrupt Si p-n junction has the p- and n- sides doped to the same level. The contact potential for the junction held at 300 K is 0.88 V.

(a) Determine the position of the Fermi energy with respect to the intrinsic Fermi energy on either side of the junction

(b) Draw the energy band diagram for the p-n junction and indicate the following: Intrinsic Fermi Energy(E_i), Fermi Energy (E_F), conduction and valence band edges.

(c) Determine the maximum electric field existing in the depletion region.

(8 marks)

Assume for Si: $n_i = 10^{10}$ cm^{-3} at 300 K, dielectric constant for Si = 11.7, $\varepsilon_o = 8.85 \times 10^{-14}$ Farad / cm

Q2. Differentiate between Zener breakdown and avalanche breakdown mechanism. State one application of Zener diode.

(2 marks)

Q3. A Si p^+-n junction has the p- and n- sides doped to 10^{19} cm^{-3} and 10^{16} cm^{-3} respectively. The junction is held at 300 K. Initially the junction is at zero bias. It is observed that when a certain forward bias voltage V is applied, the junction capacitance increases by a factor of 1.5.

(a) Determine the amount of bias (V) applied.

(b) What is the zero bias capacitance?

(c) Determine the depletion width in the presence of the bias V

(6 marks)

Assume for Si: $n_i = 10^{10}$ cm^{-3} at 300 K, dielectric constant for Si = 11.7, $\varepsilon_o = 8.85 \times 10^{-14}$ Farad / cm