BITS, PILANI – DUBAI
DUBAI INTERNATIONAL ACADEMIC CITY

EEE C381 – ELECTRONIC DEVICES AND INTEGRATED CIRCUITS YEAR III

Test I **Date: 12 October 2008** **Max marks: 25** **Weightage: 25%**

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

Q1 (a) Define Fermi-Dirac probability function *f(E)*.

(b) For a semiconductor in thermal equilibrium, 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.

If $P_e = 100\ P_h$, $T = 300$ K, and the mid band energy $E_{mid} = (E_c + E_v)/2$, how far away is the Fermi level E_F from E_{mid}? Assume that E_F is far away from the band edges.

(c) In a lightly doped Si, the probability of electrons occupying states at an energy kT above the conduction band edge E_c is e^{-10}. Is the semiconductor n-type or p-type? Determine the position of the Fermi level in the material with reference to the conduction band edge E_c. Assume room temperature.

(7 marks)

Q2 (a) Explain how phosphorus and boron atoms doped in Si can act as n-type and p-type impurities respectively.

(5 marks)

(b) A certain intrinsic semiconductor has an electron mobility μ_n that is three times the hole mobility μ_p. The electron and hole concentrations in the intrinsic semiconductor are both equal to n_i. Write down an expression for the intrinsic conductivity σ_i for the semiconductor.

The semiconductor is now doped with a certain type of impurity. The equilibrium electron and hole concentrations n_o and p_o respectively are not the same. However, it is now observed that the conductivity of this doped semiconductor is the same as the intrinsic conductivity σ_i. Show that this is possible only if $n_o = n_i/3$ and $p_o = 3n_i$.

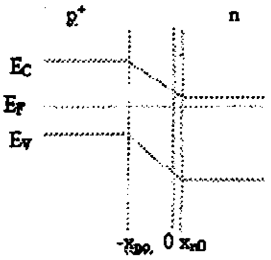
With what type of impurity has the semiconductor been doped: donor or acceptor?

(5 marks)

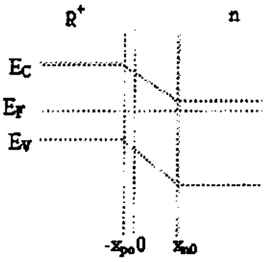
Q3 A Si p^+-n junction is formed with $N_A = 10^{18}$ cm^{-3} for the p-side and $N_D = 10^{16}$ cm^{-3} for the n-side. The junction is in thermal equilibrium at T = 300K.

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

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



(i)



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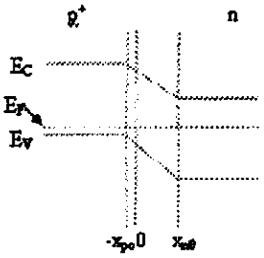
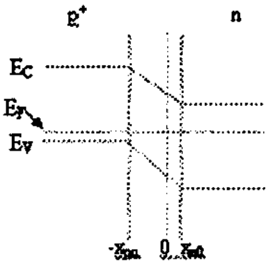


(iii)



(iv)

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

(5 marks)

Q4. A piece of p-type doped silicon at 300 K has an acceptor concentration of 5×10^{14} cm^{-3} By shining light, a low level injection of excess carriers are produced such that Δp is 1% of its thermal equilibrium value. Determine the location of the quasi Fermi level for holes, E_{Fpq} with respect to E_F

(3 marks)

END OF PAPER

LIST OF SELECTED FORMULAE

$$\boxed{f(E)=\frac{1}{1+\exp\left[\dfrac{E-E_F}{k_BT}\right]}}$$

$$V_o=\frac{kT}{q}\ln\frac{N_AN_D}{n_i^2}$$

$$W=\sqrt{\frac{2\varepsilon_s}{q}\left[\frac{N_A+N_D}{N_AN_D}\right](V_o-V)}$$

$$N_Ax_{po}=N_Dx_{no}$$

$$W=|x_{po}|+x_{no} \qquad \varepsilon_s=\varepsilon_o\varepsilon_r \qquad C_j=\frac{A\varepsilon_s}{W}$$

Physical Constant	Symbol	Value	Units
Electronic Charge	q	1.6×10^{-19}	C
Boltzmann's constant	k	8.62×10^{-5}	eV/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 at 300 K	n_i	$1.5\text{x}10^{10}$	cm^{-3}

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EEE C381 – ELECTRONIC DEVICES AND INTEGRATED CIRCUITS YEAR III

Test II (Open Book) Date: 23 Nov 2008 Max marks: 40 Weightage: 20%

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

Q1 A Si solar cell of area 2.5 cm × 2.5 cm is connected to drive a load *R* as in Figure 1. It has an I-V characteristics as shown in Figure 2

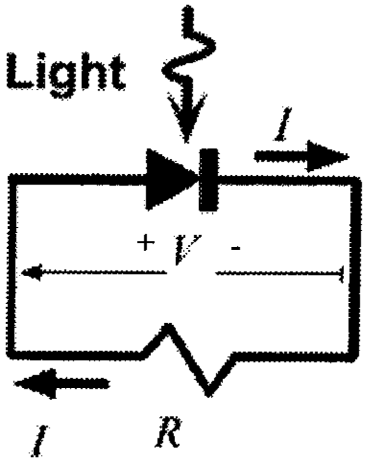


Figure 1

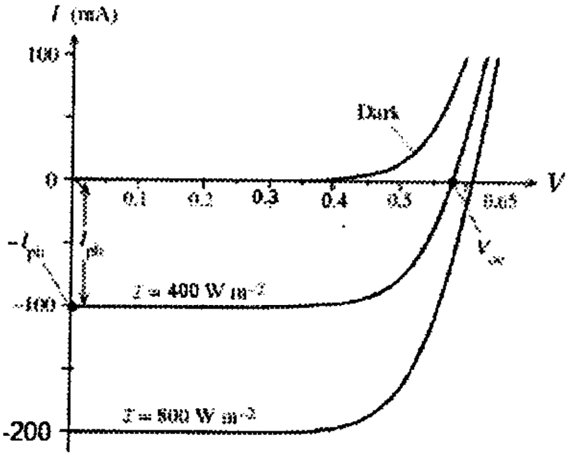


Figure 2

(a). Highlight the importance of the fourth quadrant in the I-V characteristics and explain how the device can supply power to the load R.

(5 marks)

(b) Suppose that the load is 2 Ω and it is used under a light intensity of 800 W m^{-2}. Draw the load line and determine graphically the current I and the voltage V in the circuit. What is the power delivered to the load? What is the efficiency of the solar cell in this circuit?

(7 marks)

(c). From the graph, estimate the maximum power that can be transferred from the solar cell to the load at 800 W m^{-2} illumination.

(3 marks)

(d) Consider using a number of such solar cells to drive a calculator that needs a minimum of 3 V and draws 3.0 mA at 3-4 V. It is to be used at a light intensity of about 400 W m^{-2}. How many solar cells would you need and how would you connect them?

(5 marks)

Q2 The emitter, base and collector of a silicon p^+-n-p bipolar transistor are uniformly doped with impurity concentrations of 10^{18} cm^{-3}, 10^{16} cm^{-3} and 10^{15} cm^{-3} respectively. The metallurgical base width is 0.7 μm. The transistor is operated at 300 K.

(a) Sketch the energy band diagram for the transistor in **thermal** equilibrium. Calculate the built-in potentials across the emitter-base and collector-base junctions and indicate the same in the energy band.

(6 marks)

(b) The transistor is now operated in the active mode. The emitter-base junction has a forward bias of 0.65 V. For a certain collector-base reverse bias V_{CB}, the neutral base width extends from $x = 0$ to $x = 0.3$ μm where $x = 0$ corresponds to the edge of the emitter-base depletion region in the base. Making appropriate assumptions, determine the injected minority carrier concentration in the base at x = 0. Also determine the applied reverse bias V_{CB}.

(9 marks)

Q3. Write down a general expression for the threshold voltage of a non-ideal MOS structure and explain briefly each of the four terms that contribute to it. Hence state why the threshold voltage for a NMOS is positive , while for a PMOS it is negative.

(5 marks)

Physical Constant	Symbol	Value	Units
Electronic Charge	q	1.6×10^{-19}	C
Boltzmann's constant	k	8.62×10^{-5}	eV/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 at 300 K	n_i	1.5×10^{10}	cm^{-3}

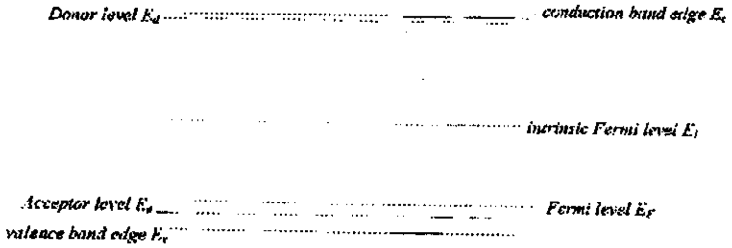
END OF PAPER

BITS-PILANI DUBAI CAMPUS
EEE-C381 EDIC YEAR III SEMESTER 1 2008-09
QUIZ NO. 1

Time: 15 minutes Maximum Marks: 10 ANSWER ALL QUESTIONS

Name of Student: ______________________ ID No: ______________

1.(2 MARKS) A semiconductor is doped with both acceptor and donor atoms. In the band diagram given below both acceptor and donor levels are indicated.



(a) What is the overall nature of the semiconductor: n-type, p-type or intrinsic?

b) Under what condition is the intrinsic energy E_i exactly at the middle of the bandgap ?

2. (3 MARKS) (a) A p-n junction is held at thermal equilibrium. Explain why a contact potential is formed across the junction

(b) If the p-side is heavily doped compared to the n-side, which side does the depletion region mainly extend into?

(c) Explain what will happen to the p-n junction if the temperature is gradually increased.

3. (5 MARKS) Differentiate between direct and indirect band gap semiconductors. List two semiconductors in each category.

BITS-PILANI DUBAI CAMPUS
EEE-C381 EDIC YEAR III SEMESTER 1 2008-09
QUIZ NO. 2

Time: 15 minutes Maximum Marks: 5 ANSWER ALL QUESTIONS

Name of Student: ______________________________ ID No: ____________________

1. (1 MARKS) A n-channel JFET has its source and gate grounded, and drain connected to a positive supply. Draw a cross section of the JFET and indicate the depletion regions for the following cases: (a) $V_D = 0V$ b) V_D = small positive and c) V_D = large positive

2.(2 MARKS) Draw the energy band diagram of a n-channel MOS structure and indicate with appropriate band bending, the onset of strong inversion Also draw the distributions of (a) Charge density, (b) electric field and (c) electrostatic potential along the entire MOS structure

3. (2 MARKS) The acceptor doping concentration for a n-channel MOS structure is increased by a factor of 2. By how much would the potential at the semiconductor – oxide interface increase or decrease? Assume room temperature.

Write down all factors that contribute to the threshold voltage in a MOS. State the signs (positive or negative) of each term for n- and p-channel MOS structures

BITS-PILANI DUBAI CAMPUS
EEE-C381 EDIC YEAR III SEMESTER 1 2008-09
QUIZ NO. 3

Time: 15 minutes Maximum Marks: 15 Weightage: 5%

ANSWER ALL QUESTIONS

Name of Student: ______________________________ ID No: ____________________

1. (8 MARKS) Starting from a bare wafer (fig 1) it is desired to make a pattern of silicon dioxide (fig 2). 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?

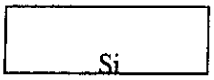


Fig 1

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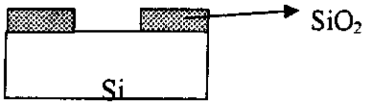
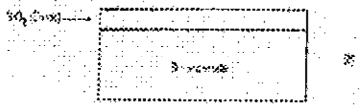


Fig 2

1. Oxidize silicon surface
2. Deposit photoresist
3. Anneal photoresist
4. Mount mask above silicon
5. Expose to UV light
6. Develop photoresist
7. Etch photoresist exposed to UV
8. Etch SiO$_2$ through photoresist hole
9. Remove photoresist

1


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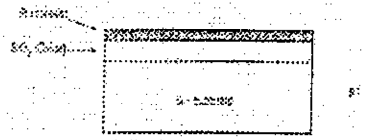

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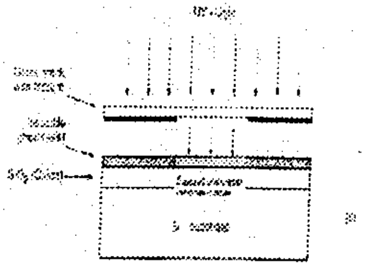

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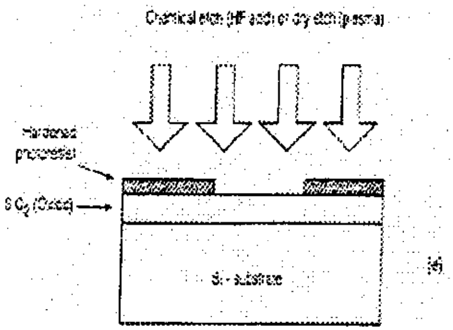

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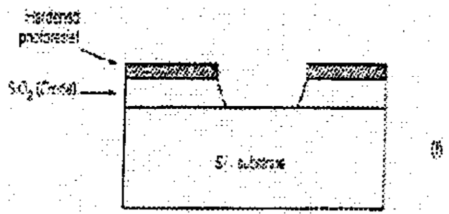

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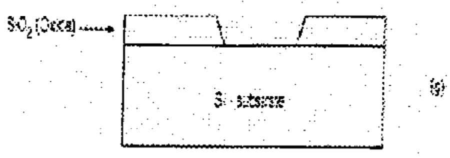

Describe photo lithography — 3 marks
Each step - 1/2 mark — 4 1/2 marks
-ve photoresist mask — 1/2 mark
8 marks.

2.(7 MARKS) An IC die measuring 1 cm x 1 cm is to be packaged in a quad flat package. The bonding pads are uniformly distributed along the periphery with a pitch of 0.1 mm.. How many pin connections will the IC have?

The layout for the IC is now changed to allow the die to be packaged in a BGA package. Noting that the total pin count is the same as before, how much will the pitch be now?

State two advantages and two disadvantages of flip chip bonding.

To find pin connection for quad flat package — $2\frac{1}{2}$ marks

To find revised pin connection for BGA package — $2\frac{1}{2}$ marks

Advantages & disadvantages — 2 marks

BITS, PILANI – DUBAI
DUBAI INTERNATIONAL ACADEMIC CITY
SEMESTER I 2008-2009

CLASS: III EEE **Date: 06 01 2009**

COURSE NO. / TITLE: EEE C381 / ELECTRONIC DEVICES AND INTEGRATED CIRCUITS
COMPREHENSIVE EXAMINATION

Max marks: 80 Weightage: 40% Time allowed: 3 hours Instructor: PROF SWAMINATHAN

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

Q1 Explain the process of formation of a depletion region in a p-n junction at thermal equilibrium. Hence discuss the origin of the built-in potential across the junction and sketch the energy band diagram of the junction. In the band diagram, indicate the following: (i) equilibrium Fermi level, (ii) built-in potential, and (iii) depletion region width.

(10 marks)

Q2 A silicon p-n abrupt junction is formed with equal doping of donors and acceptors in its n- and p- sides respectively ($N_d = N_a$). The junction is maintained in thermal equilibrium at 350 K. The built-in potential is found to be 0.8V. Calculate the following:

(i) The donor and acceptor doping densities, N_d and N_a.
(ii) The width of the depletion region, W.
(iii) The peak electric field, $\mathscr{E}_o$ inside the depletion region. Where exactly in the depletion region is the electric field maximum?

(10 marks)

Q3. In the expressions for the electron concentration n_n in an n-type semiconductor and the hole concentration p_p in a p-type semiconductor, replace the Fermi energy E_F by the intrinsic Fermi energy E_i to indicate the electron and hole concentrations in an intrinsic semiconductor. Hence show that the intrinsic Fermi energy E_i is slightly displaced from the mid band level by an amount $(3/4)kT.\ln(m_p^*/m_n^*)$, where m^*_n and m^*_p are the effective mass of electrons and holes in the semiconductor respectively. Assuming that this displacement is negligible, estimate the probability that a state at the bottom of the conduction band in an intrinsic sample of silicon is occupied by an electron at room temperature.

(10 marks)

Q4. (a) 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 would a solar cell be supplying maximum power to a load?

(10 marks)

(b) Two identical solar cells are connected in series and uniformly illuminated by light of intensity 400 W.m^{-2}. A load R of 20 ohms is connected as shown in Figure 1. Under the influence of light, each solar cell delivers a current I, with a voltage V_S across it. The I-V characteristics for each solar cell is shown in Figure 2.

(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 each solar cell is operating at 10% efficiency, determine the active area of the junction exposed to light.
(iv) If it is desired to maximize the power delivered to the load, estimate the typical load resistance that is to be used.

Note: Question No. 4 continues on page 2

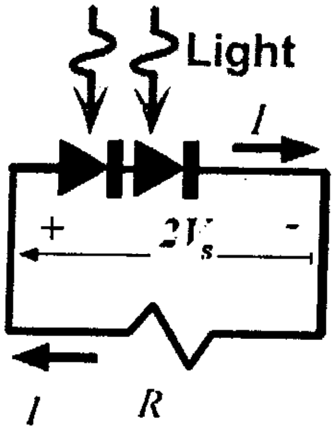

Figure 1

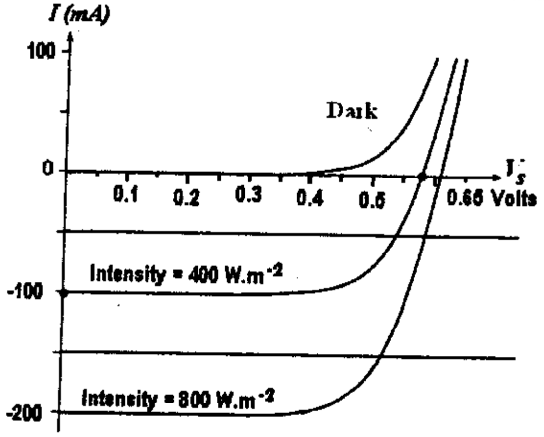

Figure 2

(15 marks)

Q5. (a) Briefly describe the operation of a tunnel diode. Draw the I-V characteristics and explain why the current exhibits a maximum and a minimum in the forward bias region. Hence discuss the importance of the negative resistance region.

(15 marks)

(b) Consider the energy band diagram of a tunnel diode at zero bias where the Fermi levels on both the n- and p-sides are aligned. Taking the conduction band edge on the n-side as a reference ($E_{cn} = 0$ eV), it is observed that the equilibrium Fermi Level is located at 0.1 eV ($E_{Fn} = 0.1$ eV) and the valence band edge on the p-side is located at 0.2 eV ($E_{Vp} = 0.2$ eV). Draw the band diagram at thermal equilibrium and hence calculate the amount of forward bias needed to produce (i) maximum tunneling current, and (b) minimum tunneling current.

(10 marks)

END OF PAPER

LIST OF SELECTED FORMULAE AND PHYSICAL CONSTANTS

$$\boxed{f(E) = \frac{1}{1+\exp\left[\frac{E-E_F}{k_B T}\right]}} \qquad V_o = \frac{kT}{q}\ln\left(\frac{N_a N_d}{n_i^2}\right) \qquad W = \sqrt{\frac{2\varepsilon_s}{q}\left[\frac{1}{N_a}+\frac{1}{N_d}\right](V_o - V)} \qquad N_c = 2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2}$$

$$p_p = N_v e^{-(E_F - E_v)/(kT)} \qquad n_n = N_c e^{-(E_c - E_F)/(kT)} \qquad N_v = 2\left(\frac{2\pi m_p^* kT}{h^2}\right)^{3/2}$$

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	1.5×10^{10} at 300 K 3.16×10^{11} at 350 K	cm^{-3}
Bandgap of Si	E_g	1.12	eV