D. J. SANGHVI COLLEGE OF ENGINEERING
DEPARTMENT OF ELECTRONICS ENGINEERING
EXC302: ELECTRONIC DEVICES SEM III
QUIZ 1 SET B SOLUTION

N.B. : **[Total Marks: 100]**

1) For every incorrect answer **50% marks** will be deducted.

2) While answering the numericals, writing formula is mandatory.

NAME: ______________________ **SAP ID:** ______________________

Given: $n_i = 1 \times 10^{10}/cm^3$, $\epsilon_s = 10^{-12}F/cm$, $\dfrac{KT}{q} = 0.026V$, $q = 1.6 \times 10^{-19}$ C

1. For a BJT in saturation mode, which of the following is true. **[02]**

   a) Both the EB and BC junctions are reversed biased

   b) **Both the EB and BC junctions are forward biased**

   c) EB junction is forward biased and BC junction is reverse biased.

   d) EB junction is reverse biased and BC junction is forward biased.

2. How do you bias a BJT to put it into saturation mode and into cutoff mode? Why are these modes useful? **[02]**

   ▶ **Bias BJT in saturation mode by forward biasing E-B junction.**

   ▶ **Bias BJT in cut-off mode by forward biasing B-C junction.**

   ▶ **BJT can be used as digital logic switches in these modes.**

3. For a BJT operating in forward-active mode, which of the following statements are incorrect? **[02]**

   a) $I_C \cong I_B$

   b) $I_B < I_E$ ✓

   c) $I_C < I_E$

   d) $I_E \cong I_c$ ✓

   e) The width of the Base W_B is much smaller than the minority carrier diffusion length L_p so that the minority carriers survive diffusion through the base. ✓

4. Now consider a pnp BJT in which the base contact is floating (i.e not electrically connected to anything). We put the emitter at 0V and apply a negative voltage V_C to the collector. Which of the following statements are true: **[02]**

   a) A very large current flows between the emitter and the collector.

   b) **A very small current flows between the emitter and the collector.**

   c) No current flows between the emitter and the collector.

   d) The B-C junction is forward biased.

   e) **The B-C junction is reverse biased.**

   Explanation: Because there is no current applied at the base, the emitter cannot inject carriers into the base and into the collector. As a result, a large current cannot flow between the emitter and the collector. However, there will still be current running through the BJT because the minority carriers between the B-C junction will be able to move across the junction due to the reverse bias.

5. You have a silicon pnp bipolar junction transistor in which you measure a base current of 20μA when the collector current is 4mA in forward-active mode.

    a) What is the emitter current? **[01]**

    i_E (in mA): **4.02 mA**

    b) What is the common emitter current gain of the transistor? **[01]**

    $$\beta = \frac{I_C}{I_B} = \mathbf{200}$$

    b) What is the common base current gain of the transistor? **[01]**

    $$\alpha = \frac{I_C}{I_B} = \mathbf{0.995}$$

6. How are the PN junctions biased in the forward-active region of a pnp BJT? **[02]**

    a) **E-B: forward biased B-C: reverse biased**

    b) E-B: forward biased B-C: forward biased

    c) E-B: reverse biased B-C: reverse biased

    d) E-B: reverse biased B-C: forward biased

7. Which of the following would be considered as a good value of β ? **[02]**

    a) 0.099

    b) 0.99

    c) 1.5

    d) 5

    e) **200**

8. Which of the following would be considered as a good value of α ? **[02]**

    a) 0.099

    b) **0.99**

    c) 1.5

    d) 5

    e) 200

9. Which of the following would be considered as a good value of emitter injection efficiency (γ) w.r.t BJT ? **[02]**

   a) 0.099

   b) **0.99**

   c) 1.5

   d) 5

   e) 200

10. Which of the following is the definition of the emitter injection efficiency γ of an NPN BJT ? **[02]**

    a) $\gamma = I_{CN}/\left(I_{EN}\right)$

    b) $\gamma = I_{CP}/\left(I_{EP}\right)$

    c) $\gamma = I_{EP}/\left(I_{EP} + I_{EN}\right)$

    d) $\gamma = I_{EN}/\left(I_{EP} + I_{EN}\right)$ ✓

11. Which of the following is the definition of the base transport factor b or α_T of an NPN BJT ? **[02]**

    a) $\alpha_T = I_{CN}/\left(I_{EN}\right)$ ✓

    b) $\alpha_T = I_{CP}/\left(I_{EP}\right)$

    c) $\alpha_T = I_{EP}/\left(I_{EP} + I_{EN}\right)$

    d) $\alpha_T = I_{EN}/\left(I_{EP} + I_{EN}\right)$

12. What is the order of highest doping, next highest doping and lightest doping in a BJT? **[02]**

    a) Collector,base,emitter

    b) **Emitter,base,collector**

    c) Emitter,collector,base

    d) Base,collector,emitter

13. How is the transconductance of a transistor defined ? **[02]**

    a) The change in output current divided by the change in output voltage.

    b) The change in input current divided by the change in input voltage.

    c) The change in output voltage divided by the change in output current.

    d) **The change in output current divided by the change in input voltage.**

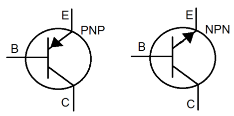
14. Which two of the following would increase the emitter injection efficiency ? **[02]**
    a) **Increasing the emitter doping**
    b) Increasing the base doping
    c) Decreasing the collector doping
    d) Decreasing the emitter doping

15. Derive the relation: $\alpha = \beta/(1+\beta)$ **[02]**

$$I_E = I_C + I_B \qquad \alpha = \frac{I_C}{I_E}$$
$$I_B = I_E - I_C$$
$$I_B = I_E - \beta I_B \qquad I_C = \beta I_B$$
$$I_B\,(1+\beta) = I_E$$
$$I_B\,(1+\beta) = \frac{I_C}{\alpha}$$
$$\alpha = \frac{I_C}{I_B\,(1+\beta)} = \frac{\beta}{1+\beta}$$

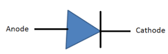
16. Which of the following are Non-ideal effects in BJT ? **[01]**
    a) **Base width modulation.**
    b) Constant energy band-gap.
    c) Low level injection.
    d) **Non-uniform base doping.**
    e) **High level injection.**

17. Draw the symbol of following : **[02]**
    a) NPN BJT

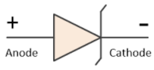


    b) PNP BJT

    c) PN diode



    d) Zener diode



18. In ED lab, you have performed experiment on Zener as voltage regulator ? **[02]**

a) What was the definition of line regulation

Line regulation: It is a measure of ability of the output voltage to remain constant irrespective of the variations in line voltages.

B) What was the formula of load regulation

$$\% \text{ Load regulation} = \left(\frac{V_{NL} - V_{FL}}{V_{NL}}\right) \times 100$$

19. In ED lab, you have performed experiment on npn BJT input I-V and output I-V characteristics in common emitter configuration ? **[02]**

Plot those input and output I-V characteristics.

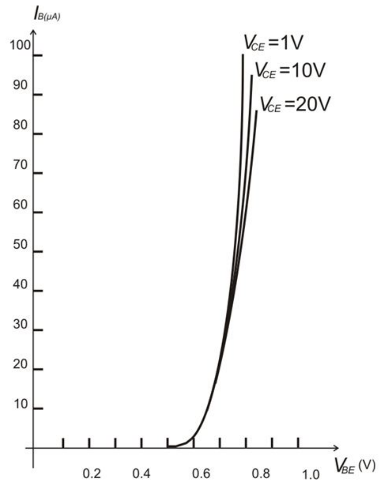


Figure 1: Input Characterictics

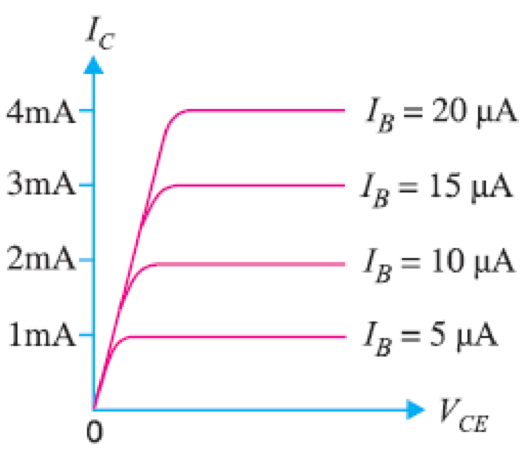
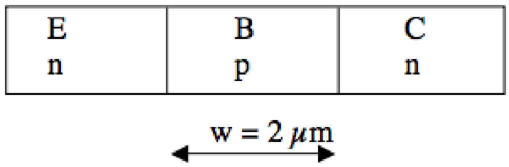


Figure 2: Output Characterictics

20. Consider a Silicon npn BJT with the following doping levels:

Emitter $N_{D,E} = 10^{18} cm^{-3}$
Base $N_{A,B} = 10^{15} cm^{-3}$
Collector $N_{D,C} = 10^{15} cm^{-3}$

Note that B and C have the same doping level. The width W of the p-type base region is $2\mu m$, as shown on the diagram.



1. Which junction has the larger depletion region? **[02]**
   a) The emitter-base junction has the larger depletion region.
   b) **The base-collector junction has the larger depletion region.**
   c) The depletion regions are of equal size.
   d) We don't have enough information to determine which depletion region is larger.

2. What is the width of the B-C depletion region in the unbiased case? **[02]**
   (Please use $n_i = 1 \times 10^{10}/cm^3$ for the intrinsic carrier concentration of Si.)

$$V_{bi} = \frac{KT}{q} ln\left(\frac{N_{A,B}N_{D,C}}{n_i^2}\right) = \mathbf{0.598\ V}$$

$$W_{A,B} = \sqrt{\frac{2\epsilon_s V_{bi}}{q}\left(\frac{N_{A,B}+N_{D,C}}{N_{A,B}N_{D,C}}\right)} = \mathbf{1.22 \times 10^{-4}cm}$$

3. Suppose we reverse bias the BC junction by applying 5V. What is the width of the B-C depletion region? **[02]**

$$W_{A,B} = \sqrt{\frac{2\epsilon_s\left(V_{bi}+V_R\right)}{q}\left(\frac{N_{A,B}+N_{D,C}}{N_{A,B}N_{D,C}}\right)} = \mathbf{3.74 \times 10^{-4}cm}$$

21. What does p_{no} mean ? **[01]**
   a) Equilibrium electron concentration in p-type semiconductor.
   b) Equilibrium hole concentration in p-type semiconductor.
   c) **Equilibrium hole concentration in n-type semiconductor.**
   d) Equilibrium electron concentration in n-type semiconductor.
   e) Equilibrium electron concentration

22. Which of the following statements is true about the magnitude of the electric field in the transition region of an PN junction ? **[01]**

a) It is constant in space.

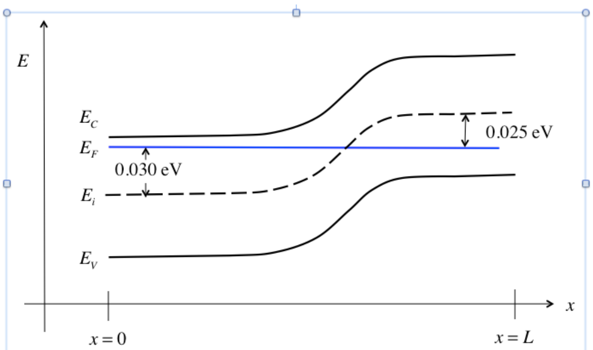
b) **It first decreases linearly, reaches a peak at the junction, then increases linearly.**

c) It first increases linearly, reaches a peak at the junction, then decreases linearly.

d) It increases linearly from the N side to the P side.

e) It decreases linearly from the N side to the P side.

23. For the energy band digram below, answer the following questions.



a) Is the potential at $x = 0$ more or less positive than the potential at $x = L$? **[02]**

Explain your answer.

A positive potential lowers the bands. At x = 0, E_C is lower than at x = L, so **the potential at x = 0 must be more positive than the potential at x = L**

b) What is the magnitude of the built-in potential? **[02]**

From the energy band diagram, the amount of band bending is the potential barrier V_{bi}

$qV_{bi} = 0.03 \text{ eV} + 0.025 \text{ eV}$

$V_{bi} = 0.03 \text{ V} + 0.025 \text{ V}$

$V_{bi} = \mathbf{0.055V}$

24. For a Si pn homojunction $N_A = 10^{18}/cm^3$ and $N_A = 10^{17}/cm^3$ at T=300K.

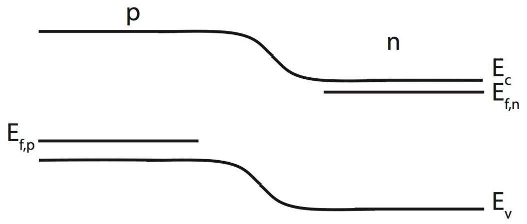
a) Calculate the built-in potential for the junction. **[02]**

$$V_{bi} = \frac{KT}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right) = \mathbf{0.89\ V}$$

b) Now calculate the depletion region width (in μm) for the junction. **[02]**

$$W = \sqrt{\frac{2\epsilon_s V_{bi}}{q}\left(\frac{N_A + N_D}{N_A N_D}\right)} = 1.1 \times 10^{-5} cm = \mathbf{0.11}\ \mu m$$

25. Consider the band diagram shown below, and then answer the following questions:



a) Is the semiconductor at equilibrium ? **[02]**

If yes, explain why ?

If no, explain why ?

Answer: No, because fermi level is not flat throughout the semiconductor.

b) What is the direction of electron diffusion ? **[02]**

The electrons diffuse from left to right

The electrons diffuse from right to left

There is no net electron diffusion current

c) What is the direction of electron drift? **[02]**

The electrons drift from left to right

The electrons drift from right to left

There is no net electron drift current

d) What is the direction of hole diffusion? **[02]**

The holes diffuse from left to right

The holes diffuse from right to left

There is no net hole diffusion current

e) What is the direction of hole drift? **[02]**

The holes drift from left to right

The holes drift from right to left

There is no net hole drift current

Explanation: 1. Carriers diffuse from areas of high concentration to areas of low concentration. 2. Electrons drift down the band. 3. Holes drift up the band.

26. You have a Si pn junction diode at room temperature with $N_A = 10^{19}/cm^3$ and $N_D = 10^{18}/cm^3$. (You may assume the following carrier mobilities for Silicon: $\mu_p = 70cm^2/Vs$ and $\mu_n = 250cm^2/Vs$. You may also assume a minority carrier lifetime of $\tau_n = \tau_p = 10^{-8}s$ for both electrons and holes, and $n_i = 10^{10}cm^{-3}$.)

a) What is the diffusivity of the holes in the Silicon? **[01]**

D_p (in cm^2/s): **1.82**

$D_p = V_T\ \mu_p = 1.82\ cm^2/s$

b) What is the diffusivity of the electrons in the Silicon? **[01]**

D_n (in cm^2/s): **6.5**

$D_n = V_T\ \mu_n = 6.5\ cm^2/s$

c) What is the minority carrier diffusion length for holes? **[01]**

L_p (in cm): **1.34** $\times 10^{-4}$

$L_P = \sqrt{D_P\ \tau_p} = 1.34 \times 10^{-4}\ cm$

d) What is the minority carrier diffusion length for electrons? **[01]**

L_n (in cm): **2.55** $\times 10^{-4}$

$L_N = \sqrt{D_N\ \tau_n} = 2.55 \times 10^{-4}\ cm$

e) Calculate J_0 for the diode described above? **[02]**

J_0 (in A/cm^2): **2.58** $\times 10^{-13}$

$$J = q\left[\frac{D_P}{L_P}p_{n0} + \frac{D_N}{L_N}n_{p0}\right] = 2.58 \times 10^{-13} A/cm^2$$

f) Use the ideal diode equation to predict the current density when a forward bias of 0.45V is applied to the diode? **[02]**

J (in A/cm^2): **8.477** $\times 10^{-6}$

$$J = J_0\left(e^{\frac{V_A}{V_T}} - 1\right) = 8.477 \times 10^{-6} A/cm^2$$

g) Use the ideal diode equation to predict the current density when a reverse bias of -10V is applied to the diode? **[02]**

J (in A/cm^2): $-$**2.58** $\times 10^{-13}$

$$J = J_0\left(e^{\frac{V_R}{V_T}} - 1\right) = -2.58 \times 10^{-13} A/cm^2$$

27. Indicate whether the following applied voltages produce a forward- or a reverse-biased p-n junction: **[02]**

a) Positive voltage is applied to the p-side: **Forward bias**

b) Negative voltage is applied to the p-side: **Reverse bias**

c) Positive voltage is applied to the n-side: **Reverse bias**

d) Negative voltage is applied to the n-side: **Forward bias**

28. Calculate the current through a silicon diode at room temperature for the following cases. Assume $I_0 = 2 \times 10^{-13}$ A.

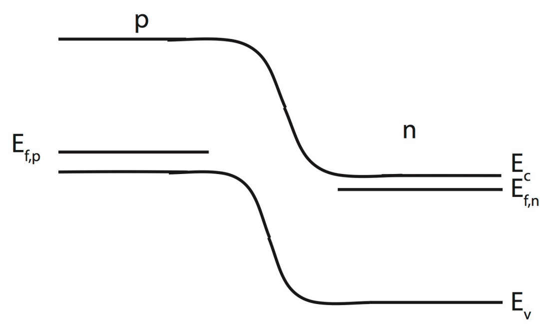
a) When a voltage of +0.3V is applied to the p-side of the junction. **[01]**

$$I = I_0 \left(e^{\frac{V_A}{V_T}} - 1 \right) = \mathbf{0.0205 \times 10^{-6}\ A}$$

a) When a voltage of −10V is applied to the p-side of the junction. **[01]**

$$I = I_0 \left(e^{\frac{V_R}{V_T}} - 1 \right) = \mathbf{-\ 2 \times 10^{-13}\ A}$$

29. Consider the band diagram shown below, and then answer the following questions:



What is the band diagram representing ? **[02]**

a) Forward-bias case.

b) **Reverse-bias case.**

c) Un-biased case.

30. What is the physical meaning of the area under E(x) vs x in a pn junction ? (Note E(x) is the Electric field as a function of distance x) **[02]**

a) It is the total doping density in the depletion region.

b) It is equal to the band-gap of the semiconductor.

c) It is the net space-charge density in the depletion region.

d) **It is the built-in potential of the junction.**

31. A Si diode is symmetrically doped at $N_A = N_D = 10^{16} cm^{-3}$. Answer the following questions assuming room temperature, equilibrium conditions and the depletion approximation.

Compute V_{bi} **[02]**

$$V_{bi} = \frac{KT}{q} \ln \left(\frac{N_A N_D}{n_i^2} \right) = \mathbf{0.718\ V}$$

Compute x_n, x_p and W **[04]**

$$W = \sqrt{\frac{2\epsilon_s V_{bi}}{q}\left(\frac{N_A + N_D}{N_A N_D}\right)} = \mathbf{4.236 \times 10^{-5} cm}$$

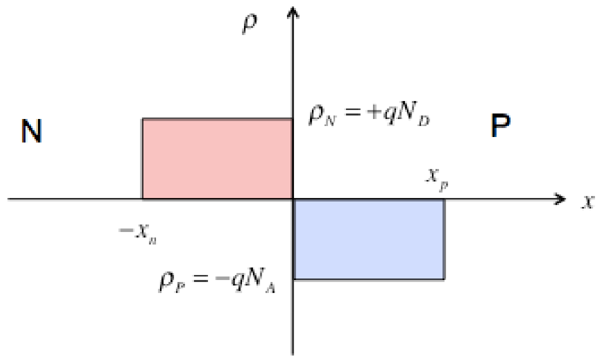
$$x_N = \left(\frac{N_A}{N_A + N_D}\right) W = \mathbf{2.12 \times 10^{-5} cm}$$

$$x_P = \left(\frac{N_D}{N_A + N_D}\right) W = \mathbf{2.12 \times 10^{-5} cm}$$

Compute E(x=0) **[02]**

$$E(\text{x=0}) = -\frac{2V_{bi}}{W} = \mathbf{-\ 33.899 \times 10^3\ V/cm}$$

Sketch ρ(x) vs. x **[02]**



32. Which of the following is true about impact ionization ? **[02]**
    a) It is the cause of avalanche breakdown.
    b) It can be initiated by either electrons or holes.
    c) It generates both electrons and holes.
    d) **All of the above.**
    e) None of the above.

33. What effect does quantum mechanical tunneling have on a PN junction ? **[02]**
    a) It can lead to reverse breakdown at low voltages.
    b) It is the cause for zener breakdown.
    c) It occurs in a heavily doped diode.
    d) **All of the above.**
    e) None of the above.

34. Which of the following is true about the small signal model of a PN junction ? **[02]**

a) It consists of a resistor in series with a capacitor.

b) **It consists of a resistor in parallel with a capacitor.**

c) It consists of a resistor in series with a inductor.

d) It consists of a resistor in parallel with a inductor.

35. Which of the following is true about the diffusion resistance in the small signal model of a PN junction diode ? **[02]**

a) It has very large value in reverse bias and a very small value in forward bias.

b) It is equal to $(dI_D/dV_A)^{-1}$

c) In forward bias, it is very close to (V_T/I_D)

d) **All of the above.**

e) None of the above.

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