Roll No.:........................

National Institute of Technology, Delhi

Name of the Examination: B. Tech

Branch	: ECE	**Semester**	: III
Title of the Course	: Solid State Devices	**Course Code**	: ECB 201

Time: 3 Hours **Maximum Marks: 50**

- **Questions are printed on BOTH sides. Answers should be CLEAR AND TO THE POINT.**
- **All parts of a single question must be answered together. ELSE QUESTION SHALL NOT BE EVALUATED.**

Section A

Choose the appropriate answer and write on the answer sheet only.

1. (a) Common base current gain can be increased by enhancing the **injection efficiency/ base transport factor/both of the above**. **[1x10=10]**

   (b) Carrier recombination in E-B depletion region **increases/ decreases** injection efficiency.

   (c) As reverse bias increases, collector current **increases/ decreases/ remains same.**

   (d) Emitter injection efficiency **increases/ decreases** with increase in doping concentration at E region.

   (e) Lower base doping **increases/ decreases** base current.

   (f) BJT Operation is controlled by carrier transport in base through **diffusion/drift** process.

   (g) Quantum mechanics is supported by **Schrödinger equation/ Poisson's equation/ Shockley equation.**

   (h) With a phase shift of 90°, Lissajous figure at CRO will produce an **ellipse/ circle/ trapezoid.**

   (i) In a CRO in sweep rate frequency is 100 Hz with 2 full sinusoidal cycles observed, then frequency of the input vertical voltage will be **100 Hz/ 200 Hz/ 1000Hz.**

   (j) At pinch-off situation of a JFET, pinch-off voltage refers to the corresponding **gate-source voltage/ drain source voltage/ gate- drain voltage**.

Section B

Write brief note on following:

2. (a) Thermal runaway **[2x5=10]**
   (b) Base width narrowing and early effect.
   (c) Depletion mode MOSFET
   (d) Tunnel diode
   (e) Hall effect

Section C

3. In a very long p-type Si bar with area = 0.5 cm^2 and Na = $10^{17}/cm^3$, holes are injected such that steady state excess hole concentration becomes 5 x $10^{16}/cm^3$ at x=0. What is the separation between E_{Fp} (Quasi Fermi Level for holes) and E_c at x=1000Å? [μp= 500 cm^2/ V-sec, Eg1.1eV] [3]

4. (a) An n- type Si semiconductor sample having with equilibrium carrier concentration, n_o= $10^{14}/cm^3$. After steady shining of light, let optically generated EHP's are 10^{13} EHP/cm^3/μs when τ_n = τ_p= 1μs. Calculate total e^- and hole concentrations after shining of light. [n_i=1.5 x $10^{10}/cm^3$] [5]

(b) Find the positions of Quasi-Fermi levels with respect to intrinsic energy level. Draw the energy band diagram.

5. A cylindrical Si bar has 1mm length and 0.1 mm^2 cross-section. Find conductivity and resistances for Si (ignoring minority carriers) for following cases: [2]

(a) When pure

(b) When doped with $10^{16}/cm^3$ donors. [μ_n = 1500cm^2/V·S, μ_p = 500 cm^2/V·S, n_i = 1.5x$10^{10}/cm^3$]

6. Sketch and label energy band diagrams across the Metal-Semiconductor Junction of all following cases (after contact only). [$q\chi$ = 4.0 eV, E_g=1.1eV, KT= 0.026eV, n_i= 1.5x $10^{10}/cm^3$ at 300k for Si] [7]

(a) $q\phi_m$= 4.5eV, $q\phi_m$=2eV for n-type for V= 0V, 0.2V(FB), +1V(RB)

(b) Depletion width (if any) for above cases:

7. Consider a Si p-n junction diode of area 10^{-4} cm^2 at 300k. [3]

For p-type part: N_a= 2.5x$10^{15}/cm^3$
τ_n= 10^{-6} s
μ_n = 1350cm^2/V·s

For n-type part: N_d= 5x$10^{16}/cm^3$
τ_p= 10^{-7} s
μ_p = 325 cm^2/V·s

n_i=1.5x$10^{10}/cm^3$

(a) Express I_o (Reverse Saturation Current) in terms of above diode parameters and then calculate its value.

(b) Calculate total current (I) for FB of 0.6V.

Section D

8. Explain in detail the transistor amplification process with the help of graphical analysis. [3]

9. What is the implication of p-i-n diode? How it overcomes the disadvantages of p-n diode? [2]

10. Define JFET parameters? [3]

11. Discuss briefly the formation of energy bands in an multiatomic crystal lattice. [2]

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Useful Equations

Fermi-Dirac e^- distribution: $f(E) = \dfrac{1}{e^{(E-E_F)/kT}+1} \cong e^{(E_F-E)/kT}$ for $E \gg E_F$

Equilibrium: $n_0 = \int_{E_c}^{\infty} f(E)N(E)dE = N_c f(E_c) = N_c e^{-(E_c-E_F)/kT}$

$$N_c = 2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2} \quad N_v = 2\left(\frac{2\pi m_p^* kT}{h^2}\right)^{3/2} \quad \begin{aligned} n_0 &= n_i e^{(E_F-E_i)/kT} \\ p_0 &= n_i e^{(E_i-E_F)/kT} \end{aligned} \quad n_0 p_0 = n_i^2$$

$$p_0 = N_v[1-f(E_v)] = N_v e^{-(E_F-E_v)/kT}$$

$$n_i = N_c e^{-(E_c-E_i)/kT}, \quad p_i = N_v e^{-(E_i-E_v)/kT} \quad n_i = \sqrt{N_c N_v}\, e^{-E_g/2kT} = 2\left(\frac{2\pi kT}{h^2}\right)^{3/2}(m_n^* m_p^*)^{3/4} e^{-E_g/2kT}$$

$$\begin{aligned} n &= N_c e^{-(E_c-F_n)/kT} = n_i e^{(F_n-E_i)/kT} \\ p &= N_v e^{-(F_p-E_v)/kT} = n_i e^{(E_i-F_p)/kT} \end{aligned} \qquad np = n_i^2 e^{(F_n-F_p)/kT}$$

$$\frac{d\mathscr{E}(x)}{dx} = -\frac{d^2V(x)}{dx^2} = \frac{\rho(x)}{\epsilon} = \frac{q}{\epsilon}(p - n + N_d^+ - N_a^-) \quad \mathscr{E}(x) = -\frac{dV(x)}{dx} = \frac{1}{q}\frac{dE_i}{dx}$$

$$\frac{I_x}{A} = J_x = q(n\mu_n + p\mu_p)\mathscr{E}_x = \sigma\mathscr{E}_x$$

Diffusion length: $L \equiv \sqrt{D\tau}$ Einstein relation: $\dfrac{D}{\mu} = \dfrac{kT}{q}$

Continuity: $\dfrac{\partial p(x,t)}{\partial t} = \dfrac{\partial \delta p}{\partial t} = -\dfrac{1}{q}\dfrac{\partial J_p}{\partial x} - \dfrac{\delta p}{\tau_p} \quad \dfrac{\partial \delta n}{\partial t} = \dfrac{1}{q}\dfrac{\partial J_n}{\partial x} - \dfrac{\delta n}{\tau_n}$

For steady state diffusion: $\dfrac{d^2\delta n}{dx^2} = \dfrac{\delta n}{D_n\tau_n} \equiv \dfrac{\delta n}{L_n^2} \quad \dfrac{d^2\delta p}{dx^2} = \dfrac{\delta p}{L_p^2}$

Equilibrium: $V_0 = \dfrac{kT}{q}\ln\dfrac{p_p}{p_n} = \dfrac{kT}{q}\ln\dfrac{N_a}{n_i^2/N_d} = \dfrac{kT}{q}\ln\dfrac{N_aN_d}{n_i^2} \quad \dfrac{p_p}{p_n} = \dfrac{n_n}{n_p} = e^{qV_0/kT} \quad W = \left[\dfrac{2\epsilon(V_0 - V)}{q}\left(\dfrac{N_a+N_d}{N_aN_d}\right)\right]^{1/2}$

Junction Depletion: $C_j = \epsilon A\left[\dfrac{q}{2\epsilon(V_0 - V)}\dfrac{N_dN_a}{N_d+N_a}\right]^{1/2} = \dfrac{\epsilon A}{W}$

One-sided abrupt p^+-n: $x_{n0} = \frac{WN_a}{N_a + N_d} \simeq W$ $\qquad V_0 = \frac{qN_dW^2}{2\epsilon}$

$\Delta p_n = p(x_{n0}) - p_n = p_n(e^{qV/kT} - 1)$

$\delta p(x_n) = \Delta p_n e^{-x_n/L_p} = p_n(e^{qV/kT} - 1)e^{-x_n/L_p}$

Ideal diode: $I = qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)(e^{qV/kT} - 1) = I_0(e^{qV/kT} - 1)$

Stored charge
exp. hole dist.: $Q_p = qA\int_0^\infty \delta p(x_n)dx_n = qA\Delta p_n \int_0^\infty e^{-x_n/L_p}dx_n = qAL_p\Delta p_n$

$$I_p(x_n = 0) = \frac{Q_p}{\tau_p} = qA\frac{L_p}{\tau_p}\Delta p_n = qA\frac{D_p}{L_p}p_n(e^{qV/kT} - 1)$$

$$I_{Ep} = qA\frac{D_p}{L_p}\left(\Delta p_E \operatorname{ctnh}\frac{W_b}{L_p} - \Delta p_C \operatorname{csch}\frac{W_b}{L_p}\right)$$

$$I_C = qA\frac{D_p}{L_p}\left(\Delta p_E \operatorname{csch}\frac{W_b}{L_p} - \Delta p_C \operatorname{ctnh}\frac{W_b}{L_p}\right)$$

Substrate bias: $\Delta V_T \simeq \frac{\sqrt{2\epsilon_s qN_a}}{C_i}(-V_B)^{1/2}$

Oxide: $C_i = \frac{\epsilon_i}{d}$ $\qquad$ Depletion: $C_d = \frac{\epsilon_s}{W}$ $\qquad$ MOS: $C = \frac{C_iC_d}{C_i + C_d}$

Inversion: $\phi_s\,(\text{inv.}) = 2\phi_F = 2\frac{kT}{q}\ln\frac{N_a}{n_i}$ (6-15) $\qquad W = \left[\frac{2\epsilon_s\phi_s}{qN_a}\right]^{1/2}$

$Q_d = -qN_aW_m = -2(\epsilon_s qN_a\phi_F)^{1/2}$ (6-32) $\qquad$ At V_{FB}: $C_{FB} = \frac{C_i\,C_{\text{debye}}}{C_i + C_{\text{debye}}}$

$$\Delta p_E = p_n(e^{qV_{EB}/kT} - 1)$$
$$\Delta p_C = p_n(e^{qV_{CB}/kT} - 1)$$

$$I_B = qA\frac{D_p}{L_p}\left[(\Delta p_E + \Delta p_C)\tanh\frac{W_b}{2L_p}\right]$$

$$B = \frac{I_C}{I_{Ep}} = \frac{\operatorname{csch} W_b/L_p}{\operatorname{ctnh} W_b/L_p} = \operatorname{sech}\frac{W_b}{L_p} \simeq 1 - \left(\frac{W_b^2}{2L_p^2}\right)$$

(Base transport factor)

$$\gamma = \frac{I_{Ep}}{I_{En} + I_{Ep}} = \left[1 + \frac{L_p^n n_n \mu_n^p}{L_n^p p_p \mu_p^n}\tanh\frac{W_b}{L_p^n}\right]^{-1} \simeq \left[1 + \frac{W_b n_n \mu_n^p}{L_n^p p_p \mu_p^n}\right]^{-1}$$

(Emitter injection efficiency)

$\frac{i_C}{i_E} = B\gamma \equiv \alpha$ (7-3)

(Common base gain)

$\frac{i_C}{i_B} = \frac{B\gamma}{1 - B\gamma} = \frac{\alpha}{1 - \alpha} \equiv \beta$

(Common emitter gain)

$\frac{i_C}{i_B} = \beta = \frac{\tau_p}{\tau_t}$

(For $\gamma = 1$)