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

# National Institute of Technology, Delhi

**Name of the Examination: B. Tech (Autumn Semester 2019)**

**Branch** : ECE **Semester** : III

**Title of the Course** :Solid State Devices **Course Code** : ECB 201

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

- **Answers should be CLEAR ANDTO THE POINT.**
- **All parts of a single question must be answered together. ELSE QUESTION SHALL NOT BE EVALUATED.**

**1.** The injected excess $e^-$ concentration profile in the base region of the n-p-n BJT, biased in the active region, is linear, as shown in the figure 1. If the area of the B-E junction is $0.001\ cm^2$, $\mu_n = 800\ cm^2V^{-1}sec^{-1}$ in the base region and depletion region widths are negligible, then find the value of collector current ($I_C$). [$V_T$ = 26 mV] **[2 M]**

**2.** Find the voltage drops across each of the Si junction diodes as shown in figure 2, at room temperature. Assume that reverse saturation current flows in the circuit and magnitude of the reverse breakdown voltage is greater than 5 volts. **[4 M]**

**3.** A transistor has $I_B = 25\ \mu A, I_{CBO} = 100\ nA$ and$\beta = 100$. Calculate$\alpha, I_C, I_E,$ and$I_{CEO}$. **[4x1 = 4M]**

**4.** A Si sample is doped with acceptor impurity of given profile: $N_A = 10^{14}\exp(-ax^2)$. For$x \geq 0$, assume$a = 2/\mu m$. $x$ is the coordinate of the sample. **[4 M]**

(a) Find the expression for the electric filed and then find the values for the electric field at $x = a/2$ and $x = a$ in unit of $V/cm$. {1+1+1}

(b) Sketch and label the energy band diagram for this Si sample [$\frac{kT}{q}$ = 0.0259]. {1}

**5.** In a given semiconductor sample excess carriers are injected at $x = 0$ due to external light illumination and profile of the excess carriers $n(x)$ of the sample w.r.t., $x$ is given in the following figure 3. [$n_i = 1.5 \times \frac{10^{10}}{cm^3}, KT = 0.026$]. **[6 M]**

(a) Predict the doping type and calculate the doping concentration of the sample in $/cm^3$. {1+2}

(b) Calculate total minority carrier concentration at $x = L_p$ in $/cm^3$. {2}

(c) Sketch and label the energy band diagram, indicating Fermi levels, if the sample is uniformly illuminated. {1}

**6.** Do the following related to CMOS logic. **[6 M]**

(a) Design a CMOS logic circuit of the arbitrary function $F = \overline{A \cdot (B + C)}$. {2}

(b) Design the truth table which supports the operation of the above logic function. {2}

(c) Do the k-Map solutions of the above logic function to ensure the corrections of your designed CMOS logic circuit in part (a). {2}

**7.** Consider an uniformly doped GaAs junction at T = 300 K. At zero bias only 20 percent of the total space charge region is to be in the p-region. The built-in potential barrier is $V_0 = 1.20$. For zero bias, determine (a) acceptor concentration, $N_A$ and (b) dopant concentration, $N_D$. [ $n_i$= $1.5\text{x}10^{16}/cm^3$, KT = 0.026]. **[3+1 M]**

8. Sketch and label energy band diagram (after contact only) across the M-S junction in following cases with proper labeling. [$q\chi$ = 4.0 eV, $E_g$ = 1.1 eV, KT = 0.026, $n_i$ = $1.5\times10^{16}/cm^3$ at 300 K for Si, $q\phi_m$ = 4.5 eV, $q\phi_s$ = 2 eV for n-type Si] **[8 M]**

(a) What is the type of contact? {1}
(b) Under no bias condition i.e. V = 0 V. {2}
(c) Under FB condition, i.e. V = 0.2 V. {2}
(d) Calculate depletion widths (if any) for V = 0 V and V = 0.2 V. {2+1}

9. A single-phase full wave rectifier uses diode. The transformer voltage is 35 $V_{rms}$ to centre tap. The load consists of 40 µF of Capacitor in parallel with a 250 $\Omega$ load resistance. Power line frequency is 50 Hz. Calculate, **[4 M]**

(a) DC current, $I_{DC}$ {3}
(b) Amplitude of ripple voltage, Vr. {1}

**10. Choose the appropriate answer and write the correct answer in the paper only.**

**(a)** Common base current gain can be increased by enhancing the **injection efficiency/ base transport factor/both of the above**. **[1x8=8 M]**

**(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 Emitter region.

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

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

**(g)** 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**.

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

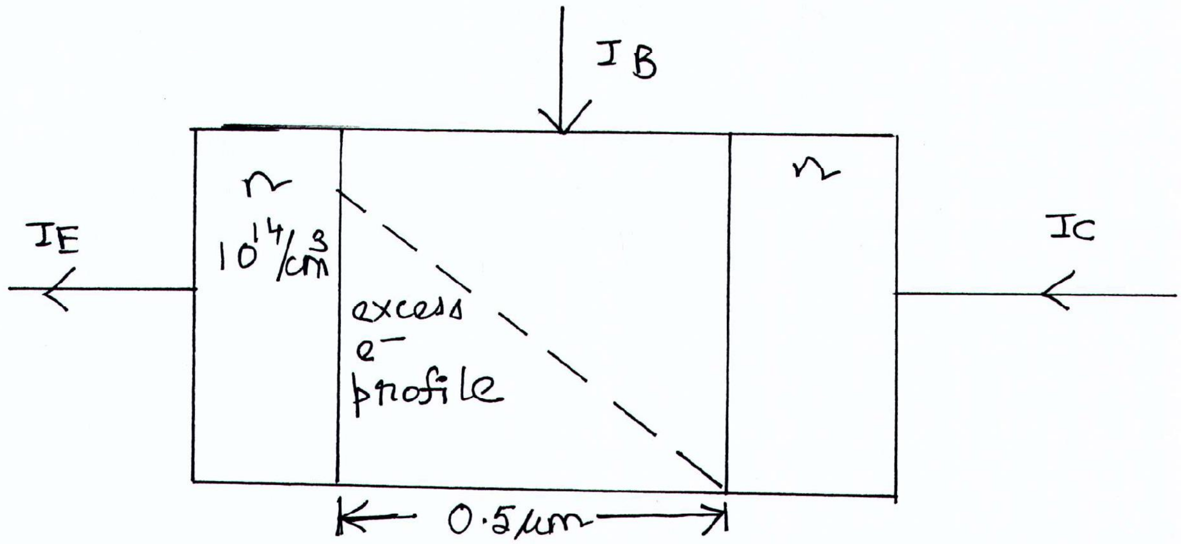


Figure 1.

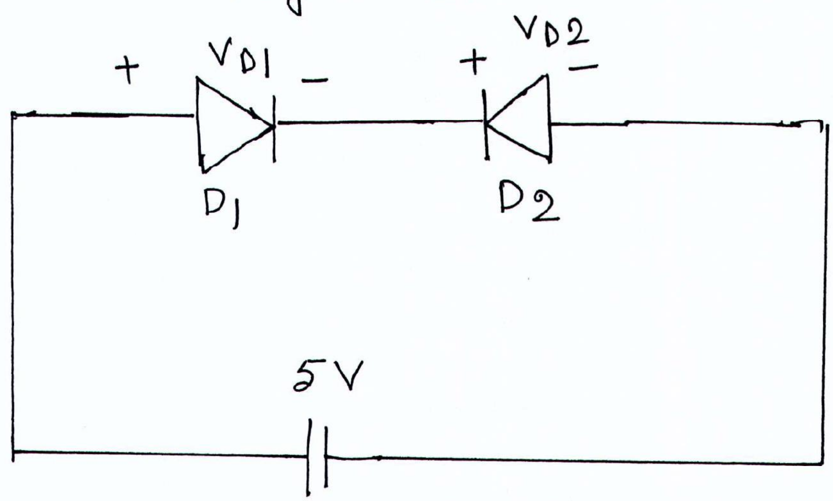


Figure 2

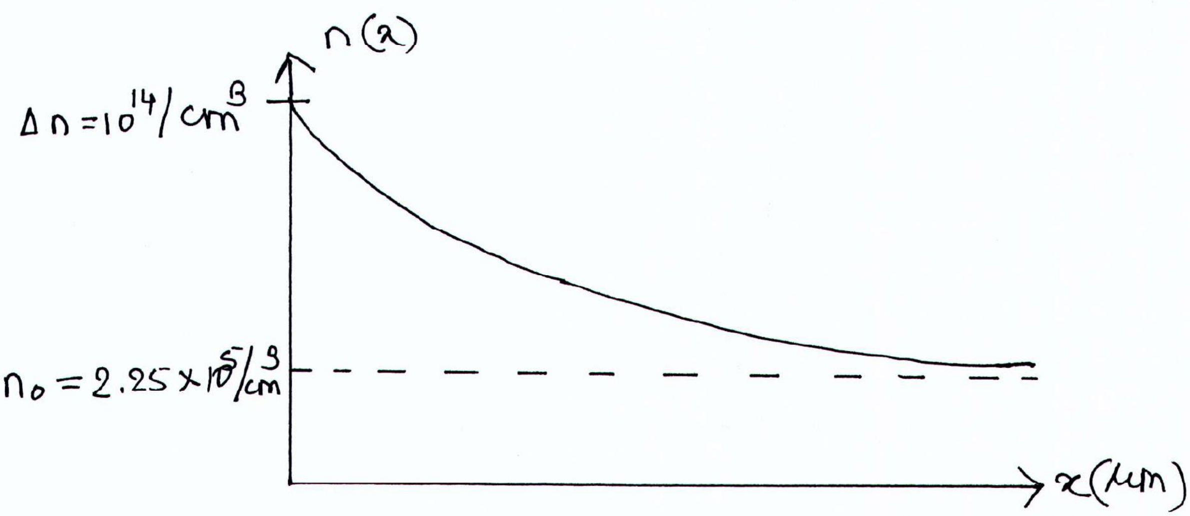


Figure 3

## Useful Equations

$r = \frac{h^2\varepsilon_0 n^2}{\pi m q^4}$ $KE = h\nu_0 - \frac{ch}{\lambda_0}$ $\rho = \frac{R.A}{L}$

$$f(E) = \frac{1}{1 + \exp\left(\frac{E - E_F}{KT}\right)}$$

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

$$N_c = 2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2} \quad n_0 = n_i e^{(E_F - E_i)/kT}$$

$N_V = 2\left(\frac{2\pi m_p^* kT}{h^2}\right)^{3/2}$ $p_0 = n_i e^{(E_i - E_F)/kT}$; $n_0 p_0 = n_i^2$

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

$n_i = N_C e^{-(E_C - E_i)/kT}$

$p_i = N_V e^{-(E_i - E_F)/kT}$ $n_i = \sqrt{N_C N_V} e^{-(E_g)/2kT} = 2\left(\frac{2\pi kT}{h^2}\right)^{3/2} (m_n^* m_p^*)^{3/4} e^{-(E_g)/2kT}$

$$n = N_C e^{-(E_C - F_n)/kT} = n_i e^{(F_n - E_i)/kT} \quad p = N_V e^{-(F_p - E_i)/kT} = n_i e^{(E_i - F_p)/kT}$$

$$np = n_i^2 e^{(F_n - F_p)/kT}$$

$$\frac{d\xi(x)}{dx} = \frac{d^2V(x)}{dx^2} = \frac{\rho(x)}{\epsilon} = \frac{q}{\epsilon}(p - n + N_d^+ - N_a^-)$$

$\xi(x) = -\frac{dV(x)}{dx} = \frac{1}{q}\frac{dE_i}{dx}\frac{I_x}{A} = J_x = q(n\mu_n + p\mu_p)\xi_x = \sigma\xi_x$ $L = \sqrt{D_\tau}$ $\frac{D}{\mu} = \frac{kT}{q}$

$$\frac{\partial p(x,t)}{\partial t} = \frac{\partial \delta p}{\partial t} = -\frac{1}{q}\frac{\partial J_p}{\partial x} - \frac{\delta p}{\tau_p}$$

$$\frac{\partial \delta n}{\partial t} = \frac{1}{q}\frac{\partial J_n}{\partial x} - \frac{\delta n}{\tau_n}$$

$$\frac{d^2\delta n}{dx^2} = \frac{\delta n}{D_n \tau_n} = \frac{\delta n}{L_n^2} \quad \frac{d^2\delta p}{dx^2} = \frac{\delta p}{L_p^2}$$

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

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

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

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

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

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

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: $C_i = \frac{\epsilon_i}{d}$ Depletion: $C_d = \frac{\epsilon_s}{W}$ 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) $\qquad W = \left[\frac{2\epsilon_s\phi_s}{qN_a}\right]^{1/2}$