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**

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

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1. Answer the changes in each of the following parameters in terms of "Increasing" or "Decreasing" as the case may be, **when temperature increases**. [10 x 1]
   - (a) Conductivity of the semiconductor.
   - (b) Reverse saturation current in p-n junction.
   - (c) Junction potential.
   - (d) Junction width.
   - (e) Energy bad gap.
   - (f) Junction capacitance.
   - (g) Mobility due to impurity.
   - (h) Conductance of JFET channel.
   - (i) Pinch off voltage.
   - (j) Avalanche breakdown.

2. A Si p-type substrate at room temperature shows a current density of 24 A/cm^2 for an applied field of 10 V/cm. The same substrate is used to make a p-n junction which provides a junction potential of 0.6 V. [2+2+4+2]
   - (a) Find the dopant concentration of the substrate.
   - (b) Find the dopant type and concentration required for the n-side of the junction.
   - (c) Draw the majority and minority carrier concentration profile across the above p-n junction for both unbiased (V = 0) and reverse biased conditions.
   - (d) Draw the energy band diagram of the above p-n junction formed for both unbiased (V = 0) and forward biased ($V_f = 0.2\ V$) conditions.

3. A Si sample is doped with acceptor impurity of given profile: $N_A = 10^{14}\exp(-ax^2)$. For $x \geq 0$ assume a = $2/(\mu m)^{1/2}$. [3+3]
   - (a) Find the expression and value for the electric field at x = $a/2$ and at x = a.
   - (b) Sketch and label the energy band diagram for this Si sample.

4. Sketch and label the energy band diagram across metal semiconductor junction. (Assume: $q\chi$ for semiconductor is $4.0\ eV$, $E_g = 1.1\ eV$, $kT = 0.026\ eV$, $n_i = 1.5 \times 10^{10}/cm^3$ at 300 K. [1+1+2+2]

   (a) $q\phi_m = 4.5\ eV$, $q\phi_s = 4.2\ eV$ for n-type for V = 0 V, 0.2 V (forward bias), 1 V (reverse bias)

   (b) $q\phi_m = 4.3\ eV$, $q\phi_s = 4.4\ eV$ for n-type for V = 0 V, 0.2 V (forward bias), +1 V (reverse bias)

   (c) Depletion width if any for both the cases.

   (d) Find the maximum electric field at the interface.

5. Sketch the I-V curve for a real diode and comment for: [3]

   (a) Reverse saturation current increases with bias.

   (b) Forward current varies with a function exp $(qV/2kT)$.

   (c) Under high level injection.

6. For a p-n junction diode the maximum electric filed is given as [5]

$$E_{max} = \sqrt{\frac{2q(V_o - V)N_A.N_D}{\epsilon_s(N_A + N_D)}}$$

   Derive the expression for breakdown voltage V_{Br} for a p^+n diode in terms of E_{max}. Assume, $E_{max} = E_{critical}$.

   Comment on breakdown voltage (V_{Br}) as N_D is increased.

7. Draw and label properly the energy band diagram of a junction made by two different materials A and B whose data are given below [2]

Material	Elec. Affinity (eV)	$E_g(eV)$	$E_C - E_F\ (eV)$	$E_F - E_V\ (eV)$
A (p-type)	4.5	1.4	-	0.3
B (n-type)	4.5	1.8	0.3	-

8. The current equation for a p-n junction diode for $V > \frac{3kT}{q}$ is given as, $I = I_o \exp\left(\frac{qV}{kT}\right)$ where, $I_o = A.exp\left(\frac{-1.12\ eV}{kT}\right)$. Calculate the suitable forward bias voltage required at 320 K for this diode to maintain the same current as available in this diode at 300 K for 0.5 V forward bias. Hence, compute $\frac{\Delta V}{\Delta T}$. [3]

9. Draw the gate label schematic of binary half adder circuit. Draw its equivalent CMOS transistor-based circuit. Write down the Boolean expression and truth table, which explain properly both the above drawn circuit. [5]

Useful Equations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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: $x_{n0} = \frac{WN_a}{N_a + N_d} \simeq W$ $\quad V_0 = \frac{qN_dW^2}{2\epsilon}$

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

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

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) $\quad W = \left[\frac{2\epsilon_s\phi_s}{qN_a}\right]^{1/2}$