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: 2 Hours		**Maximum Marks: 25**	

- **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.**

Use following data if not given in a problem: ε_o = 8.85x10^{-14}F/cm, ε_r (SiO_2) = 3.9, ε_r (Si) = 11.8, At room temperature for Si [μ_n = 1350cm^2/V·S, μ_p = 480 cm^2/V·S, n_i = 1.5x10^{10}/cm^3, E_g = 1.12 eV], k = 8.62 x10^{-5} eV/K, $\tau_n = \tau_p$= 1μs, E_g(Ge) = 0.7 eV, n_i(Ge)= 2.5x10^{13} /cm^3.

1. Derive the expression for the electric field and built in potential across a linearly graded *pn* junction diode having physical contact at x=0. The space charge profile is given as $\rho(x) = qax$, where, x is the distance with $|x| = \pm x_0$ from x = 0 on either of the sides and a is constant. [4]

2. In an abrupt Si *pn* junction diode area 10^{-4} cm^2 has doping concentration as N_a=10^{17} /cm^3 and N_d=10^{18} /cm^3. Diode has forward bias of 1Volt. Mobility for electrons and holes are μ_n = 1350 cm^2/V-sec and μ_p =400 cm^2/V-sec, respectively. $\tau_n = \tau_p = 10\,ns$. Find excess carrier concentrations. [2]

3. Holes are injected in a p^+n diode with an n-region width similar to hole diffusion length L_p. Excess holes at n-side varies linearly from Δp_n (at x_n=0) to zero (at x_n=L_p). Solve diffusion equation to find excess hole concentration. [2]

4. On a Si sample light is incident at t=0 uniformly, which generates excess charge carriers for t >0. The generation rate for excess carrier is 6×10^{22}/cm^3. Sample is doped with 2×10^{17}/cm^3 As atoms. Determine the conductivity of the sample at t=5ms. Assume no external electric field is applied. μ_n =1000 cm^2/V-sec, μ_h = 420 cm^2/V-sec. [4]

5. Predict the effect of mobility and resistivity of Si crystal at room temp if every millionth of Si atom is replaced by an Indium (In) atom. Given, concentration of Si atoms is 5×10^{28}/m^3, intrinsic carrier concentration is 1.5×10^{10}/cm^3, intrinsic conductivity of Si is 0.00044 S/m, intrinsic resistivity of Si is 2300 Ωm, μ_n =0.135 m^2/V-sec, μ_p = 0.0480 m^2/V-sec, respectively. [3]

6. Comment on the following with brief and to the point logical explanation: [1+1+1+2]

   (a) Variation of band gap with doping.
   (b) Variation of band gap with temperature.
   (c) Variation of lattice controlled mobility with temp.
   (d) Variation of intrinsic carrier concentrations (n_i) with temp. and band gap (E_g).

7. Write true (T)/false (F) only against each of the following: [0.5x10 = 5]

   (a) Slow luminescence process is known as fluorescence.
   (b) Any drift, diffusion or combination of two in a semiconductor results in current

proportional to the gradients of the two quasi-Fermi levels.

(c) Depletion approximation is related to carrier depletion within space charge region.
(d) Carbon (C) is an indirect band gap semiconductor.
(e) Reverse saturation current decreases with temperature.
(f) Junction potential decreases with increasing temperature.
(g) Junction width decreases with increasing temperature.
(h) Conductivity of a semiconductor decreases with increasing temperature.
(i) Band gap (E_g) increases with increasing temperature.
(j) Avalanche breakdown increases with increasing temperature.

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

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

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

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

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

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

$$\frac{I_x}{A} = J_x = q(n\mu_n + p\mu_p)\mathscr{E}_x = \sigma\mathscr{E}_x \qquad \frac{p_p}{p_n} = \frac{n_n}{n_p} = e^{qV_0/kT} \qquad W = \left[\frac{2\epsilon(V_0 - V)}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)\right]^{1/2}$$

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

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

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

Equilibrium: $V_0 = \dfrac{kT}{q}\ln\dfrac{p_p}{p_n} = \dfrac{kT}{q}\ln\dfrac{N_a}{n_i^2/N_d} = \dfrac{kT}{q}\ln\dfrac{N_a N_d}{n_i^2}$