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National Institute of Technology, Delhi

Name of the Examination: B. Tech: Mid Semester (Autumn 2019-2020) Examination

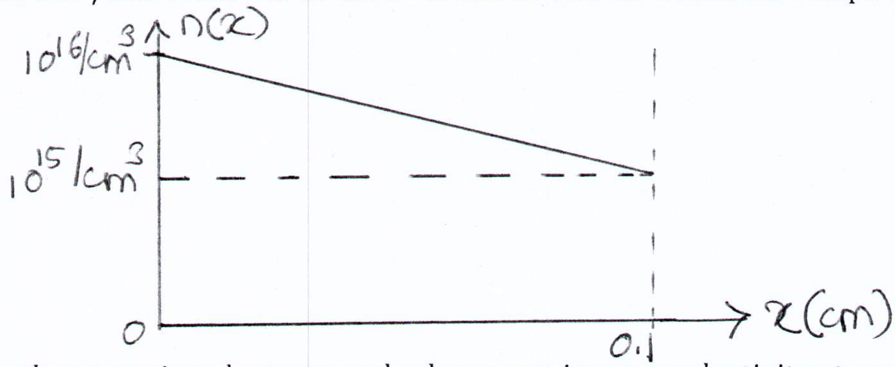
Branch	: ECE	Semester	: III
Title of the Course	: Solid State Devices	Course Code	: ECB 201
Time: 2 Hours		Maximum Marks: 25	

Note:

- **Questions are printed on BOTH sides. Answers should be CLEAR ANDTO THE POINT.**
- **All parts of a single question must be answered together and in the same sequence as given in question paper. 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.

Q1. Calculate the position of the intrinsic Fermi level w.r.t. the center of the bandgap in Si at 300 K. The density of states effective carriers masses in Si are, $m_n^* = 1.08\, m_0$ and $m_p^* = 0.56\, m_0$. **[2 M]**

Q2. The e^- concentration decreases as shown in the plot, within a Si sample. The cross-sectional area of the sample is 0.05 cm^2 and D_n for Si = 25 cm^2/sec. What will be the e^- diffusion current within the sample? **[2 M]**



Q3. Show that a semiconductor sample shows maximum conductivity at any given temperature when carrier concentrations are, $n = n_i\sqrt{\mu_h/\mu_e}$ and $p = p_i\sqrt{\mu_e/\mu_h}$, where symbols have their usual meanings. **[2 M]**

Q4. Determine the values of n_0 and p_0 for Si at T = 300 K, if the Fermi energy level is 0.22 eV above the valence band energy. [$N_V = 1.04 \times 10^{19}/cm^3$, $N_C = 2.8 \times 10^{19}/cm^3$ and $E_{g,Si} = 1.12\ eV$ at 300 K]. **[2 M]**

Q5. The bandgap (E_g) of GaAsP is 1.95 eV. Determine the wavelength of EM radiation that is emitted upon direct recombination of electrons and holes in the GaAsP sample. What will be the color of emitted radiation? **[2 M]**

Q6. Estimate the expressions for developed electric field of a Si *pn* junction where the space charge profile at depletion region is given as, p(x) = qh(2x+3) where, x is distance of the device from physical contact at x = 0 and h = Plank's constant. **[3 M]**

Q7. A Si sample is doped with 10^{16} cm^{-3} donor impurity is exposed by light at x = 0 to generate excess EHP of amount $10^{14}/cm^3$. Excess carriers travel 1 cm distance in 0.4 ms time under a field of 2 V/cm. **[2+3+2 M]**

(a) Calculate p(x) and n(x) at x = 2Lp.

(b) Calculate diffusion current density at x= 0, Lp, and 2Lp.

(c) Calculate mobility for majority and minority carriers.

[Dp = 25 cm^2/sec, Dn = 50 cm^2/sec, $\tau_n = \tau_p = 10\ ns$]

Q8. Answer the changes in each of the following parameters in terms of **increasing/decreasing only** as the case may be when *temperature increases. [no explanation required]* **[5x1 M]**

(a)Conductivity of the semiconductor

(b) Reverse saturation current in p-n Junction

(c)Junction Width

(d) Mobility due to impurity'

(e) Avalanche breakdown.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$I_C = qA\dfrac{D_p}{L_p}\left(\Delta p_E \operatorname{csch}\dfrac{W_b}{L_p} - \Delta p_C \operatorname{ctnh}\dfrac{W_b}{L_p}\right)$ Substrate bias: $\Delta V_T \simeq \dfrac{\sqrt{2\epsilon_s qN_a}}{C_i}(-V_B)^{1/2}$

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

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