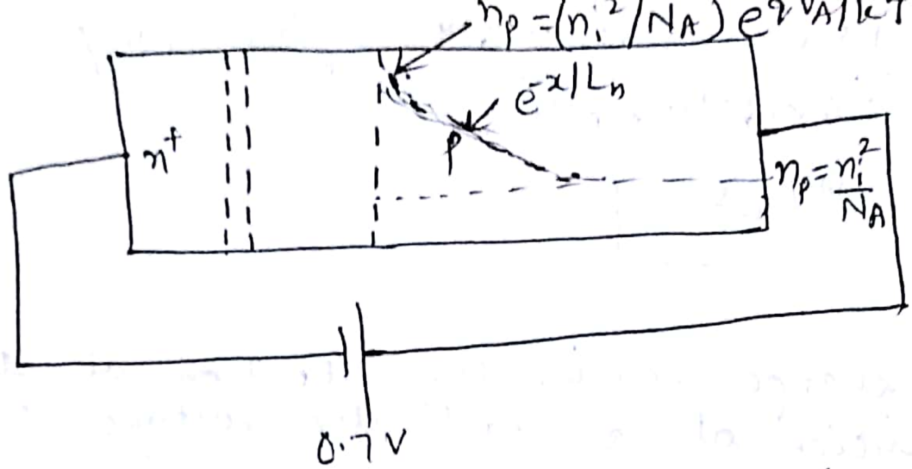
Q. 1



Total current density through the device,

$$J = q\left(\frac{D_n}{L_n}\frac{n_i^2}{N_A} + \frac{D_p}{L_p}\frac{n_i^2}{N_D}\right)\left(e^{qV_A/kT} - 1\right) \quad \text{---} (0.5)$$

far away from the junction, there is no minority charge carrier concentration gradient ⇒ negligible diffusion current. Therefore, there would be drift current given by

$$J_{drift} \approx q\mu_p p(x)\xi = q\mu_p N_A \xi \quad \text{where } \xi = \text{Electric field} \quad \text{--}(0.5)$$

To maintain current continuity, far away from junction,

$$J = J_{drift}$$

$$q\left(\frac{D_n}{L_n}\frac{n_i^2}{N_A} + \frac{D_p}{L_p}\frac{n_i^2}{N_D}\right)\left(e^{qV_A/kT} - 1\right) = q\mu_p N_A \xi$$

$$\xi = \frac{1}{\mu_p}\left(\frac{D_n}{L_n}\frac{n_i^2}{N_A^2} + \frac{D_p}{L_p}\frac{n_i^2}{N_A N_D}\right)\left(e^{qV_A/kT} - 1\right)$$

Since it is n^+p region, $N_D >> N_A$ ⇒ second term can be neglected and

$$\frac{1}{\mu_p} = \frac{kT}{qD_p} \qquad D_n = \mu_n \frac{kT}{q} \quad \text{---}(1)$$

$$\xi = \frac{kT}{qD_p}\left[\sqrt{\frac{\mu_n kT}{q\tau_n}}\left(\frac{n_i}{N_A}\right)^2\right]\left(e^{0.7/0.0258} - 1\right)$$

$$= \frac{0.0258}{13}\left(\sqrt{\frac{1000 \times 0.0258}{2\times 10^{-6}}}\right)\left(\frac{10^{10}}{10^{16}}\right)^2 \times 6.07\times 10^{11}$$

$$= 7.13\times 10^{-3} \times 10^{3} \times 10^{-12} \times 6.07\times 10^{11} = 4.327\ \text{V/cm}$$

$\frac{kT}{q} \rightarrow 0.025$ to 0.026 V ⇒ $\xi = 3.55$ V/cm to 9.79 V/cm

Q.2 a) $|V_A| = \frac{E_g}{2q} = \frac{1.12}{2} = 0.56\ V$ ---- (1)

b) $V_{bi} + V_A = \frac{E_g}{q} \Rightarrow V_{bi} = \frac{E_g}{q} - \frac{E_g}{2q}$

$\Rightarrow V_{bi} = \frac{E_g}{2q} = 0.56\ V$ ---- (1)

c) Junction recombination will constitute the recombination-generation current through the diode at the pictured bias point because diode is operating in reverse bias.

At junction, $n = p \approx 0$

$\Rightarrow \frac{\partial n}{\partial t} = +\frac{n_i}{2\tau}$ and

$I_R = -qA \int_0^W \frac{\partial n}{\partial t}\, dx$ ---- (1)

$\Rightarrow I_R = -qA \int_0^W \left(\frac{+n_i}{2\tau}\right) dx = \frac{-qAn_iW}{2\tau}$

$= -\frac{1.6 \times 10^{-19} \times 10^{-3} \times 10^{10} \times 2 \times 10^{-4}}{2 \times 10^{-6}} = -1.6 \times 10^{-10}\ A$ ---- (1)

Calculation of n_i

$W = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(V_{bi} + V_A)}$

$N_A = n_i \exp\left(\frac{E_i - F_p}{kT}\right)$, $N_D = n_i \exp\left(\frac{F_n - E_i}{kT}\right)$

$\Rightarrow N_A = n_i \exp\left(\frac{E_g}{4kT}\right) = N_D$

$n_i \exp\left(\frac{E_g}{4kT}\right) = \frac{2\varepsilon_s (V_{bi} + V_A) \times 2}{q \times W^2} = \frac{2 \times 11.8 \times 8.85 \times 10^{-14} \times 1.12 \times 2}{(1.6 \times 10^{-19}) \times (2 \times 10^{-4})^2}$

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$$n_i = \frac{11.8 \times 8.85 \times 1.12 \times 10^{-14}}{1.6 \times 10^{-27} \times \exp(10.85)}$$

$$= \frac{116.96 \times 10^{-14}}{1.6 \times 10^{-27} \times 5.15 \times 10^{4}} \approx 1.419 \times 10^{10} / cm^3$$

$\left(\frac{kT}{q} \to 0.025 \text{ to } 0.026\ ;\ n_i \to 10^{10} \text{ to } 1.5 \times 10^{10}/cm^3\right)$

(d) The excess charge carrier concentration at the edge of junction at a particular voltage bias is given by:

$$\Delta n = \frac{n_i^2}{N_A}\left(e^{qV_A/kT} - 1\right) \approx -\frac{n_i^2}{N_A} \text{ for given bias}$$

Since there is no field in the regions outside the junctions, there is constant diffusion current

$$J_n \text{ (in p-region)} \approx -qD_n \frac{n_p}{L_n}$$

$$J_p \text{ (in n-region)} \approx -qD_p \frac{p_n}{L_p}$$

Total diffusion current density

$$J_{diff} = q\left(\frac{D_n}{L_n}\frac{n_i^2}{N_A} + \frac{D_p}{L_p}\frac{n_i^2}{N_D}\right) \quad \text{---(1)}$$

$$I_{diff} = qA\left(\sqrt{\frac{D_n}{\tau_n}}\frac{n_i^2}{N_A} + \sqrt{\frac{D_p}{\tau_p}}\frac{n_i^3}{N_A}\right) \quad [N_A \approx N_D]$$

$$= qA\frac{n_i^2}{N_A}\left(\sqrt{\frac{D_n}{\tau_n}} + \sqrt{\frac{D_p}{\tau_p}}\right) \quad \text{---(1)}$$

$$= \frac{1.6 \times 10^{-19} \times 10^{-3} \times 10^{10}}{\exp(1.12/[4 \times 0.0258])}\left[\sqrt{\frac{1352 \times 0.0258}{10^{-6}}} + \sqrt{\frac{459 \times 0.0258}{10^{-6}}}\right]$$

$$= \frac{1.6}{5.16}\ \frac{\times 10^{-12}}{10^{4}}\left[5.9 \times 10^{3} + 3.44 \times 10^{3}\right]$$

$$= 2.89 \times 10^{-13} \text{ A}$$

$= 0.289$ pA (range $(kT/q \to 0.025$ to $0.026)$ 0.2 pA to 0.4 pA) (1)

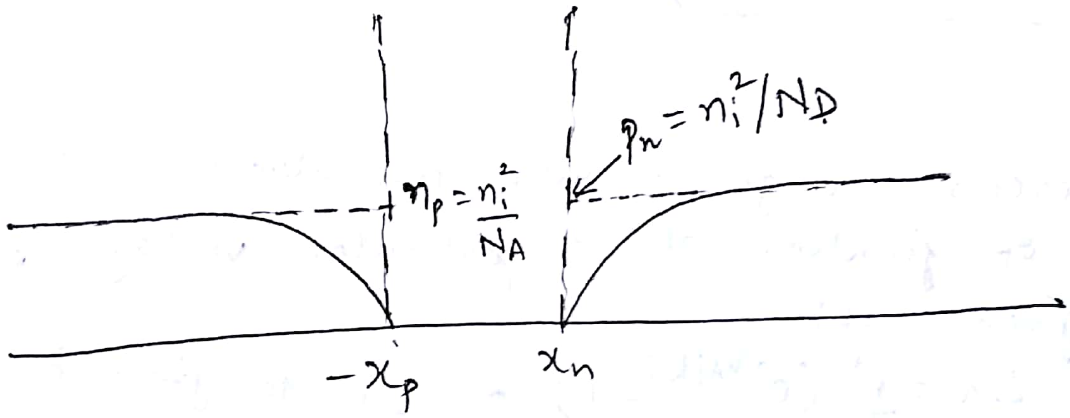
e) Junction Capacitance, $C_j = \frac{A\varepsilon}{W}$

$$W = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(V_{bi} + V_A)} = x_n + x_p = 2 \times 10^{-4}\ \text{cm}$$

$$\Rightarrow C_j = \frac{10^{-3} \times 11.8 \times 8.85 \times 10^{-14}}{2 \times 10^{-4}} = 5.22 \times 10^{-12}\ \text{F}$$

$$\Rightarrow \boxed{C_j = 5.22\ \text{pF}} \quad \text{----} \quad (1)$$

f)



(1)

g) As the reverse bias is increased, the depletion width (W) changes and hence junction capacitance (C_j). This keeps the stored charge constant resulting in negligible current change through the device.

Also, in other words,

$$I_{RB} \approx -qA\left(\frac{D_n}{L_n}\frac{n_i^2}{N_A} + \frac{D_p}{L_p}\frac{n_i^2}{N_D}\right)$$

which does not change with V.

This implies that would be no current transient characterized by storage delay time, t_s, on increasing reverse bias. ---- (1)