

## Problem 3.1

a)  $p(W_n + x_n) = 0$

b)  $p(x_n) = \frac{n_i^2}{N_d} e^{\frac{qV_0}{kT}} = 9 \times 10^{11} / \text{cm}^3$

c) Short-base Limit:

$$p'(x) = \frac{n_i^2}{N_d} \left( e^{\frac{qV_0}{kT}} - 1 \right) \left( \frac{W_n + x_n - x}{W_n} \right)$$

$$\text{Total charge} = qA \int_{x_n}^{W_n + x_n} p'(x) dx = qA \frac{n_i^2}{N_d} \left( e^{\frac{qV_0}{kT}} - 1 \right) \int_{x_n}^{W_n + x_n} (W_n + x_n - x) dx$$

$$= \frac{1}{2} qA \frac{n_i^2}{N_d} \left( e^{\frac{qV_0}{kT}} - 1 \right) W_n$$

$$= 1.4 \times 10^{-15} \text{ C}$$

d) Short-base Limit

$$\frac{\partial^2 p(x)}{\partial x^2} = 0 \Rightarrow p'(x) = \frac{n_i^2}{N_d} \left( e^{\frac{qV_0}{kT}} - 1 \right) \left( \frac{W_n + x_n - x}{W_n} \right)$$

$$J_p(0) = J_p(x_n), \quad J_p^{\text{diff}}(x) \text{ on N-side}$$

$$= -qD_p \frac{\partial p(x)}{\partial x}$$

$$= -qD_p \frac{n_i^2}{N_d} \left( e^{\frac{qV_0}{kT}} - 1 \right) \cdot \frac{-1}{W_n}$$

$$= qn_i^2 \frac{D_p}{N_d W_n} \left( e^{\frac{qV_0}{kT}} - 1 \right), \text{ which is a constant}$$

$$= 5.7 \times 10^{-3} \text{ A/cm}^2$$

e)

$$\frac{1}{2} q A \frac{n_i^2}{N_a} \left( e^{\frac{qV_D}{kT}} - 1 \right) W_p = \frac{1}{2} \times \frac{1}{2} q A \frac{n_i^2}{N_d} \left( e^{\frac{qV_D}{kT}} - 1 \right) W_n$$

$$\Rightarrow \frac{1}{N_a} = \frac{1}{2N_d} \Rightarrow N_a = 2N_d = 2 \times 10^{16} / \text{cm}^3$$

f)  $Q_d = \frac{1}{2} q A \frac{n_i^2}{N_a} \left( e^{\frac{qV_D}{kT}} - 1 \right) W_p \times 3$

$$= \frac{3}{2} q A \frac{n_i^2}{N_a} W_p \left( e^{\frac{qV_D}{kT}} - 1 \right)$$

$$C_d = \frac{\partial Q_d}{\partial V_D} = \frac{3}{2} q A \frac{n_i^2}{N_a} W_p \frac{q}{kT} e^{\frac{qV_D}{kT}}$$

$$= 8.2 \times 10^{-14} \text{ F}$$

g) Short-base Limit

$$\frac{\partial^2 n'(x)}{\partial x^2} = 0 \Rightarrow n'(x) = \frac{n_i^2}{N_a} \left( e^{\frac{qV_D}{kT}} - 1 \right) \left( \frac{W_p + x_p + x}{W_p} \right)$$

$$J_n(0) = J_n(-x_p) \quad \frac{d}{dx} \text{ on P-side}$$

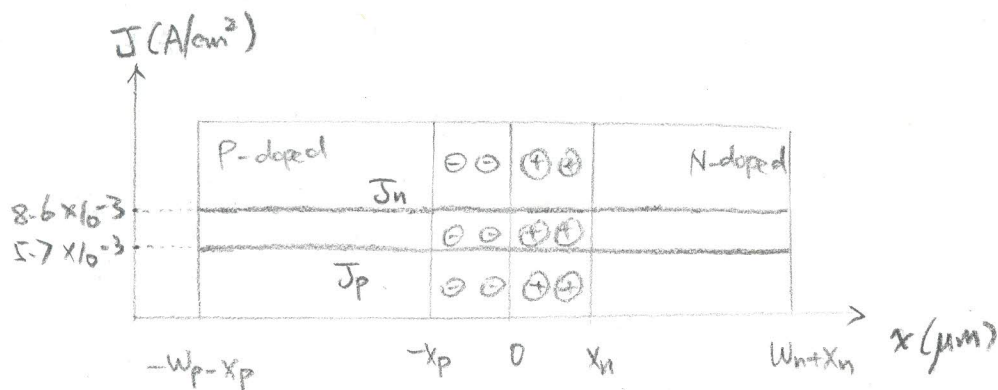
$$= q D_n \frac{\partial n'(x)}{\partial x}$$

$$= q D_n \frac{n_i^2}{N_a} \left( e^{\frac{qV_D}{kT}} - 1 \right) \frac{1}{W_p}$$

$$= 8.6 \times 10^{-3} \text{ A/cm}^2$$

$$J_n(0) / J_p(0) = \frac{D_n}{D_p} \frac{N_d W_n}{N_a W_p} = 1.5$$

h)



i) On P-side

$$p'(x) = n'(x) = \frac{n_i^2}{N_a} \left( e^{\frac{qV_D}{kT}} - 1 \right) \left( \frac{W_p + x_p + x}{W_p} \right)$$

$$J_p^{\text{diff}}(x) = -qD_p \frac{\partial p(x)}{\partial x} = -qD_p \frac{n_i^2}{N_a} \left( e^{\frac{qV_D}{kT}} - 1 \right) \frac{1}{W_p} = -2.8 \times 10^{-3} \text{ A/cm}^2$$

$$j) J_p^{\text{drif}} = J_p^T - J_p^{\text{diff}} = \frac{q n_i^2 D_p}{N_a W_n} \left( e^{\frac{qV_D}{kT}} - 1 \right) + \frac{q n_i^2 D_p}{N_a W_p} \left( e^{\frac{qV_D}{kT}} - 1 \right)$$

$$= q n_i^2 D_p \left( \frac{1}{N_a W_n} + \frac{1}{N_a W_p} \right) \left( e^{\frac{qV_D}{kT}} - 1 \right)$$

$$= 8.6 \times 10^{-3} \text{ A/cm}^2$$

$$k) J_p^{\text{drif}} = q \mu_h p_{po} E_x \quad p_{po} = N_a$$

$$\Rightarrow E_x = \frac{n_i^2}{\mu_h} \frac{D_p}{N_a} \left( \frac{1}{N_a W_n} + \frac{1}{N_a W_p} \right) \left( e^{\frac{qV_D}{kT}} - 1 \right) \quad \frac{D_p}{\mu} = \frac{kT}{q}$$

$$= \frac{n_i^2}{N_a} \frac{kT}{q} \left( \frac{1}{N_a W_n} + \frac{1}{N_a W_p} \right) \left( e^{\frac{qV_D}{kT}} - 1 \right)$$

$$= 8.7 \times 10^{-3} \text{ V/cm}$$

$$l) J_T = J_n(0) + J_p(0) = q n_i^2 \left( \frac{D_n}{N_a w_p} + \frac{D_p}{N_d w_n} \right) \left( e^{\frac{q V_D}{k T}} - 1 \right)$$

$$I_T = J_T A = 1.4 \times 10^{-6} \text{ A}$$

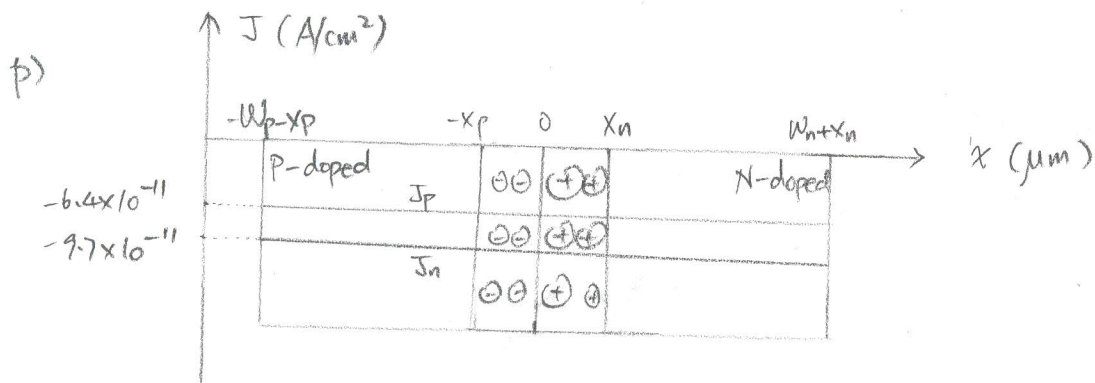
$$m) J_n(0) = 5 J_p(0) \Rightarrow \frac{J_n(0)}{J_p(0)} = \frac{D_n}{D_p} \frac{N_d w_n}{N_a w_p} = 5$$

$$\Rightarrow \frac{\mu_n}{\mu_p} \frac{N_d}{N_a} = 5 \Rightarrow N_a = \frac{\mu_n}{\mu_p} \frac{N_d}{5} = 0.6 N_d = 6 \times 10^{15} / \text{cm}^3$$

n)  $p(x)$  at metal is zero

$$o) p(x_n) = \frac{n_i^2}{N_d} e^{\frac{q V_D}{k T}}, \quad V_D = -0.476 \text{ V}$$

$$= 1.1 \times 10^{-4} / \text{cm}^3$$



$$q) J_p^{diff}(x) = -q D_p \frac{n_i^2}{N_a} \left( e^{\frac{q V_D}{k T}} - 1 \right) \frac{1}{w_p}$$

$$= 3.2 \times 10^{-11} \text{ A/cm}^2$$

$$r) J_p^{drift} = q n_i^2 D_p \left( \frac{1}{N_d W_n} + \frac{1}{N_a W_p} \right) \left( e^{\frac{q V_0}{k T}} - 1 \right)$$

$$= -9.7 \times 10^{-11} \text{ A/cm}^2$$

$$s) E_x = \frac{n_i^2}{N_a} \frac{k T}{q} \left( \frac{1}{N_d W_n} + \frac{1}{N_a W_p} \right) \left( e^{\frac{q V_0}{k T}} - 1 \right)$$

$$= -9.8 \times 10^{-11} \text{ V/cm}$$

$$t) I_T = -1.6 \times 10^{-14} \text{ A}$$