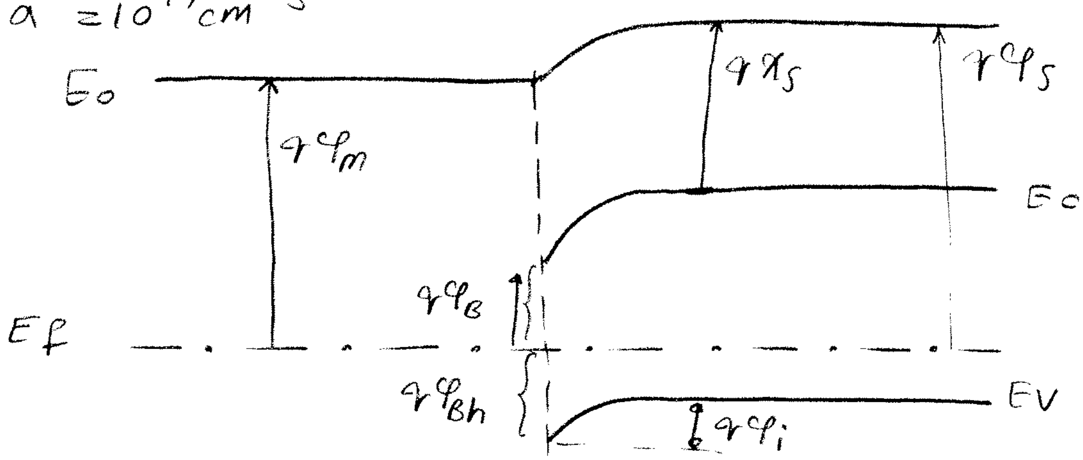
Home Work # 5

1) a) P-type Silicon, $\varphi_B = 0.38$, Schottkly Barrier

$N_a = 10^{17} cm^{-3}$



$q\varphi_{Bh} = 0.38\,eV$

we need φ_i, we need $E_f - E_V$,

$$E_f = E_V + KT \ln\left(\frac{N_V}{N_a}\right) = E_V + 0.138\,eV$$

$$q\varphi_i = q\varphi_{Bh} - (E_f - E_V) = 0.38\,eV - 0.138\,eV$$

$$= \underline{0.242\,eV}$$

b) We know that:

$$I = I_0\left(\exp\left(\frac{qV_A}{\underbrace{(1.05)}_{\text{Ideality Factor}}KT}\right) - 1\right)$$

The reverse bias current is $\underline{10^{-6} A = I_0}$

we need 1mA $\Longrightarrow$ The current needs to increase by 100 times.

$$\Longrightarrow 100 = \exp\left(\frac{qV_A}{1.05\,kT}\right) \Longrightarrow V_A = 1.05\left(\frac{kT}{q}\right)\ln(100)$$

$= \underline{0.124\ V}$ ← The forward bias needed.

c)

$$\varphi_i = \frac{1}{2} x_d |\mathcal{E}_{max}| = \frac{1}{2} \frac{qN_a}{K\epsilon_0} x_d^2$$

$$\Longrightarrow N_a = \frac{2K\epsilon_0 \varphi_i}{q x_d^2}$$

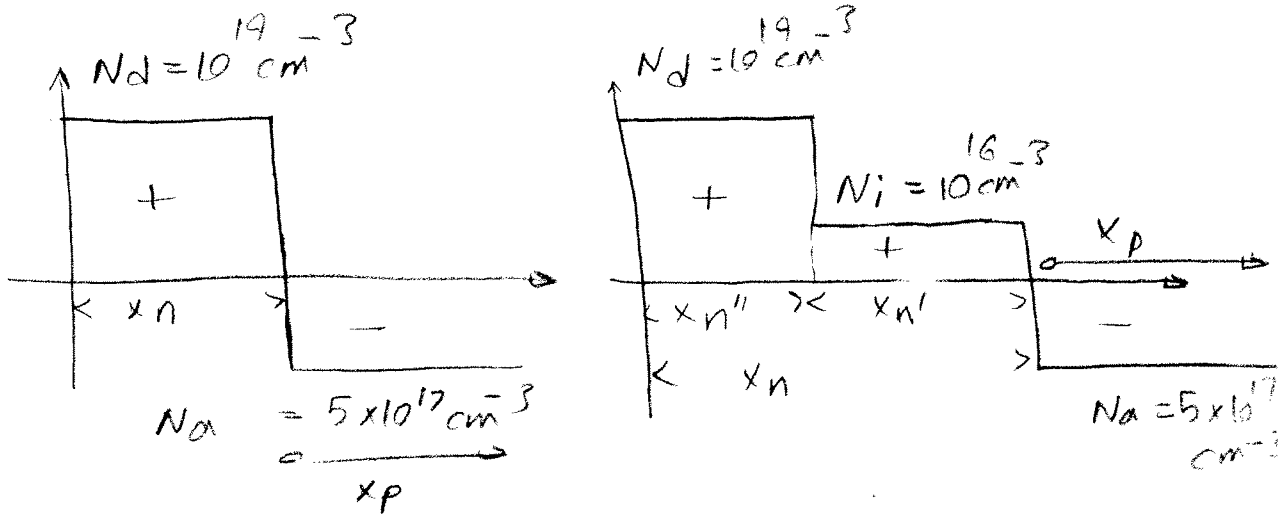
we want x_d to be 2.5nm $= \underline{2.5\times10^{-7}\ cm}$

$$\Longrightarrow N_a = \frac{2(11.7)(8.85\times10^{-14}\ F/cm)(0.242\ V)}{(1.6\times10^{-19}\ C)(2.5\times10^{-7}\ cm)^2}$$

$= \underline{5.01\times10^{19}\ cm^{-3}}$

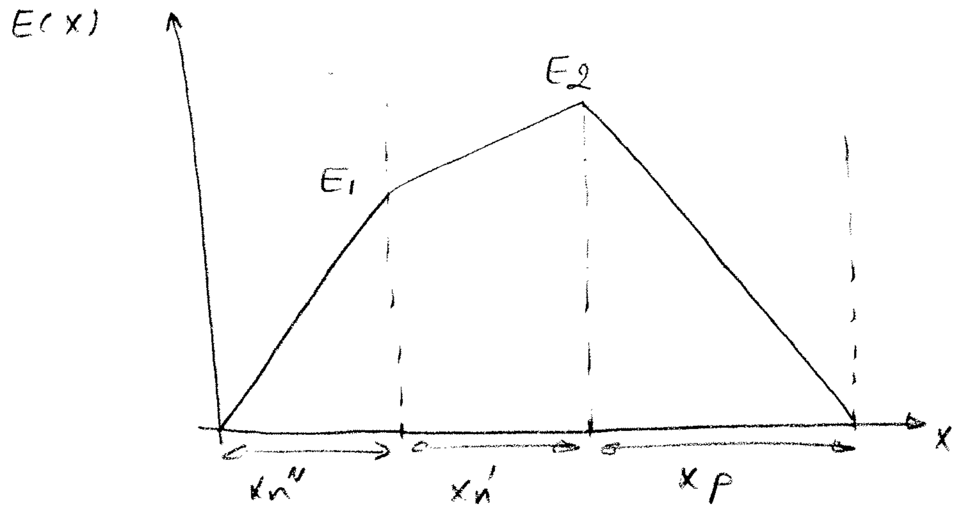
Si Pn Junction PVn Junction

2)



First we need to find x_n and x_p:

Charge Nuetrality $\Longrightarrow N_a x_p = N_i x_n' + N_d x_n''$ (1)



$$E_1 = \frac{q N_d x_n''}{K\epsilon_0} \qquad E_2 = E_1 + q\frac{N_i x_n'}{K\epsilon_0} = q\frac{N_a x_p}{K\epsilon_0}$$

$$\varphi_i = \frac{KT}{q}\ln\left(\frac{N_d N_a}{n_i^2}\right) = 0.0256\ln\left(\frac{10^{19}\times 5\times10^{17}}{10^{20}}\right) \simeq \underline{\underline{0.987}}$$

We also know that:

(3) $$\varphi_i = -\int E\,dx = -\left[\frac{1}{2}E_1 x_n'' + \left(\frac{E_1+E_2}{2}\right)x_n' + \frac{E_2 x_p}{2}\right]$$

$$\Longrightarrow \frac{2K\epsilon_0 \varphi_i}{q} = N_d X_n''^2 + N_d X_n' X_n'' + N_a X_p X_n' + N_a X_p^2 \quad (2)$$

$$(1), (2) \Longrightarrow \frac{2K\epsilon_0 \varphi_i}{q X_n'^2} = \left(\frac{X_n''}{X_n'}\right)^2 \left[N_d + \frac{N_d^2}{N_a}\right] + \left(\frac{X_n''}{X_n'}\right)\left[2N_d\left(1+\frac{N_i}{N_a}\right)\right] + N_i + \frac{N_i^2}{N_a}$$

$X_n' = 100nm = 10^{-5}\ cm$

$$\Longrightarrow 0.013 = \left(\frac{X_n''}{X_n'}\right)^2 \times 21 + \left(\frac{X_n''}{X_n'}\right)(2.04) + 1.02\times10^{-3}$$

$$\Longrightarrow \frac{X''_n}{X'_n} = 0.0055 \Longrightarrow X_n'' = 0.55nm$$

$$X_p = \frac{(10^{16} \times 10^{-5}\ cm^{-2}) + (10^{19} \times 0.55\times10^{-7}\ cm^{-2})}{5\times10^{17}\ cm^{-3}} = 1.3\times10^{-6}\ cm = \underline{\underline{13nm}}$$

2 b)

E_{max} for Pin diode is $E_2 = \frac{q}{K\epsilon_0}(N_a X_p) = \underline{\underline{1\times10^5\ Vcm^{-1}}}$

E_{max} for Pn diode is $= \left[\frac{2q\varphi_i N_A N_D}{K\epsilon_0 (N_A + N_D)}\right]^{\frac{1}{2}} = \underline{\underline{3.9\times10^5\ V/cm}}$

$E_{max,Pn} > E_{max,Pin}$

2 c) Pin, from 1(a), we see that $X_n' >> X_n'', X_p$

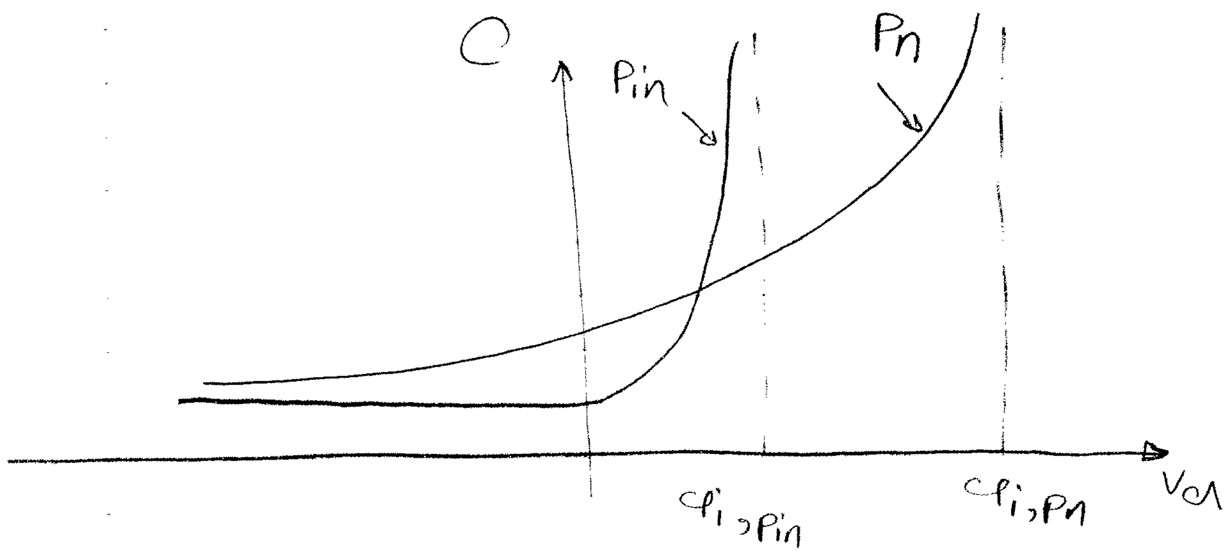
$\Longrightarrow$ The depletion region width is $X_d \simeq X_n'$

Under reverse bias, the intrinsic region is fully

(4) depleted, so, $C \simeq \frac{K\epsilon_0}{X_n'} \simeq \underline{\underline{\text{constant}}}$

as bias voltage becomes increasingly positive the intrinsic region would not be fully depleted at some point.

$$C = \left[\frac{qk\epsilon_0}{2\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(\varphi_i - V_A)} \right]^{\frac{1}{2}}$$ as $V_a \to \varphi_i \Rightarrow C \to \infty$



$$\varphi_{i,Pin} = \frac{kT}{q} \ln\left(\frac{N_i N_a}{n_i^2}\right) = 0.81V$$

$$\varphi_{i,Pn} = \frac{kT}{q} \ln\left(\frac{N_d N_a}{n_i^2}\right) = 0.98V$$

3) $N_a = 5\times10^{18}\ cm^{-3}$ $N_d = 2\times10^{17} cm^{-3}$

$\tau_n = \tau_p = 0.02\mu s$ (P-region) $W_p = 100nm = 100\times10^{-7}$ cm

$\tau_n = \tau_p = 0.5\mu s$ (n-region) $W_n = 700\mu m = 700\times10^{-4}$ cm

a) No recombination in the depletion region

In order to sketch this, we will need information for x_n, x_p, the current densities at the edges of the depletion region, and at the contacts.

It's also useful to check whether this is a long or short diode.

$N_a = 5\times10^{18} cm^{-3} \Rightarrow D_n = (\frac{KT}{q})(175 \frac{cm^2}{VS}) = 4.38\ cm^2/s$

$N_d = 2\times10^{17} cm^{-3} \Rightarrow D_p = (\frac{KT}{q})(200 cm^2/_{VS}) = 5\ cm^2/s$

$L_n = \sqrt{D_n \tau_n} = \sqrt{4.38\times0.02\times10^{-6}}\ cm = 2.96\times10^{-4} cm >> W_p$
(Short diode at P side)

$L_p = \sqrt{D_p \tau_p} = \sqrt{5\times0.5\times10^{-6}}\ cm = 1.58\times10^{-3}$ cm

To get x_n and x_p, we need φ_i :

$$\varphi_i = \frac{KT}{q} \ln\left(\frac{N_d N_a}{n_i^2}\right) = 0.921\ V$$

$\Longrightarrow$

3a)

$$x_n = \sqrt{\frac{2K\epsilon_0(\varphi_i - V_A)}{q} \frac{N_a}{N_d} \left(\frac{1}{N_a+N_d}\right)} = 3.70 \times 10^{-6}\ cm$$

$$x_p = \sqrt{\frac{2K\epsilon_0(\varphi_i - V_A)}{q} \frac{N_d}{N_a} \left(\frac{1}{N_d+N_a}\right)} = 1.48 \times 10^{-7}\ cm$$

i) $J_p(x_n) = q \dfrac{D_p P_{no}}{L_p}\left(\exp\left(\dfrac{qV_a}{kT}\right) - 1\right)$

$= (1.6 \times 10^{-19}\ c)\ \dfrac{5\ cm^2/s \times 500\ cm^{-3}}{1.58 \times 10^{-3}\ cm}\left(e^{\left(\frac{0.7}{0.025}\right)} - 1\right)$

$= \underline{0.366\ Acm^{-2}}$

ii) $J_p(x_p) = J_p(x_n) = 0.366\ Acm^{-2}$ (No recombination)

iii) $J_n(-w_p) = q \dfrac{D_n n_{po}}{W_p}\left[\exp\left(\dfrac{qV_a}{kT}\right) - 1\right] = J_n(-x_p)$

$= (1.6 \times 10^{-19}\ c)\ \dfrac{4.38 \times 20\ cm^{-1} s^{-1}}{100 \times 10^{-7}\ cm}\left[\exp\left(\dfrac{0.7}{0.025}\right) - 1\right]$

$= \underline{2.03\ A\ cm^{-2}}$

iv) $J_n(w_n) \simeq J_{total} = J_p(x_n) + J_n(-x_p)$

$= 2.4\ Acm^{-2}$

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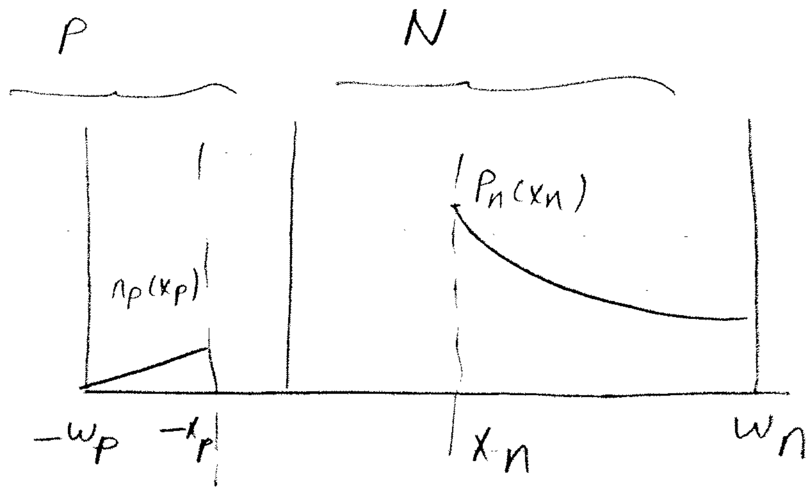
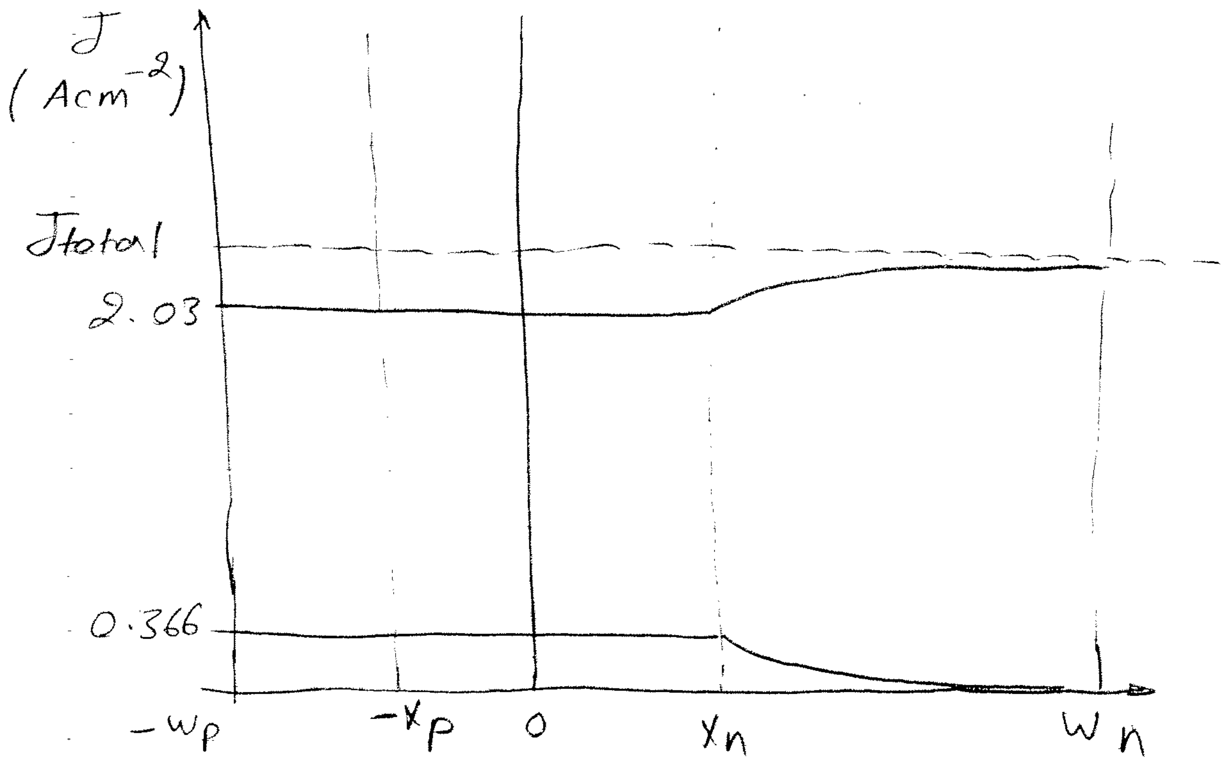
3 a)





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3 b) $V_A = 0.3V$ and we have recombination in the depletion region. $x'_d = x_d/10 = \frac{6.45}{10} \times 10^{-6}$ cm

$= \underline{\underline{0.645 \times 10^{-6} \text{ cm}}}$

(i) $J_p(x_n) = q \frac{D_p}{L_p} p_{no} \left[e^{\left(\frac{qV_a}{0.025}\right)} - 1 \right] = \underline{\underline{4.1 \times 10^{-8} \text{ Acm}^{-2}}}$

(ii) Need to calculate recombination

$$J_{rec} = \underbrace{\frac{q x_d' n_i}{2\tau_0}} \exp\left(\frac{qV_a}{2kT}\right) = \underline{\underline{4.2 \times 10^{-7}}} \text{ Acm}^{-2}$$

$\tau_n + \tau_p \rightarrow$ Using n-region values.

$\Rightarrow J_p(-x_p) = J_p(x_n) + J_{rec} \simeq \underline{\underline{4.6 \times 10^{-7}}} \text{ Acm}^{-2}$

iii) $J_n(-W_p) = q \frac{D_n n_{po}}{W_p} \left[\exp\left(\frac{qV_a}{kT}\right) - 1 \right] = 2.28 \times 10^{-7} \text{ Acm}^{-2}$

iv) $J_n(W_n) \simeq J_{total} = J_n(W_p) + J_p(-x_p) = \underline{\underline{6.9 \times 10^{-7} \text{ Acm}^{-2}}}$