HW#3 SOLUTION

1)

a) $V_{bi} = \frac{KT}{q} \ln \frac{N_A N_D}{n_i^2} = 0.716 \text{ V}$

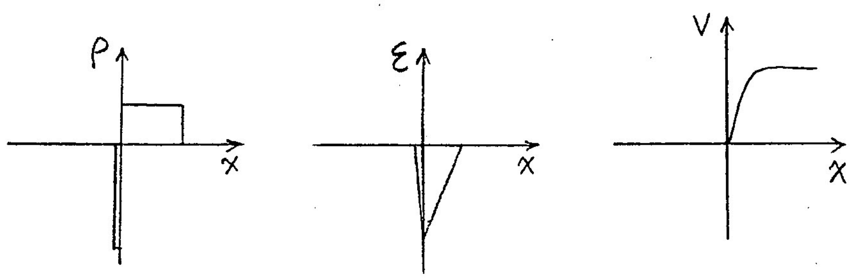
$$x_p = \left[\frac{2K_S\epsilon_0 \cdot N_D \cdot V_{bi}}{q \cdot N_A (N_A + N_D)} \right]^{1/2} = 9.62 \times 10^{-7} \text{ cm}$$

$$x_n = \left[\frac{2K_S\epsilon_0 \cdot N_A \cdot V_{bi}}{q \cdot N_D (N_A + N_D)} \right]^{1/2} = 9.62 \times 10^{-5} \text{ cm.}$$

$$W = x_n + x_p = 9.72 \times 10^{-5} \text{ cm.}$$

$$\mathcal{E}(0) = -\frac{qN_D}{K_S\epsilon_0} x_n = -1.47 \times 10^4 \text{ V/cm}$$

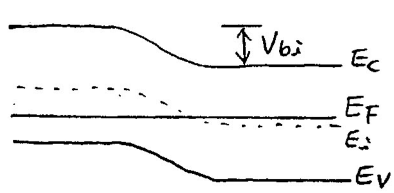
$$V(0) = \frac{qN_A}{2K_S\epsilon_0} x_p^2 = 7.09 \times 10^{-3} \text{ V}$$



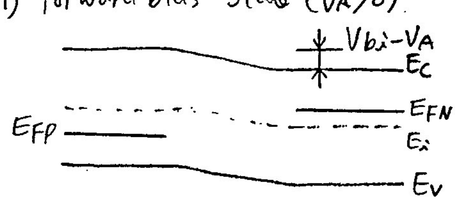
In problem 5.4, the widths of the n- and p-sides of the depletion region and the corresponding variation of the electrostatic variables are comparable reflecting the fact that $N_A \sim N_D$. Here with $N_A \gg N_D$, we find the depletion region width and potential drop lie almost exclusively on the lowly doped n-side of the junction.

b) For banddiagram, consider the Quasi-Fermi level, E_{FP}, E_{FN} first.

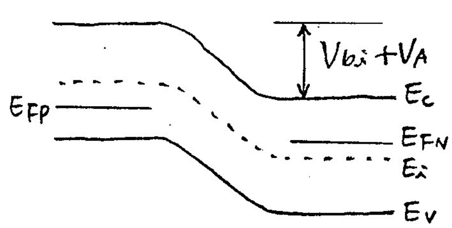
i) equilibrium state



ii) forward bias state ($V_A > 0$)



iii) revers bias state ($V_A < 0$)



2) prob. 6.1 a) ~ f)

a) Majority carrier injection (diffusion) to the opposite side of the junction.

b) Minority carriers wandering into the depletion region and being accelerated (drifting) to the opposite side of the junction.

c) the reverse bias current is expected to be small because it arises from minority carriers which are few in number. the revers bias current saturate because a small voltage all but eliminates majority carrier injection across the junction, and the remaining current due to minority carriers is independent of the applied voltage.

d) generation and diffusion.

e) The primary reason is that $\mathcal{E} \neq 0$. Also, low level injection conditions seldom apply: $\partial n/\partial t|_{thermal\ R\text{-}G} \neq -\Delta n_p/\tau_n$ and $\partial p/\partial t|_{thermal\ R\text{-}G} \neq -\Delta p_n/\tau_p$

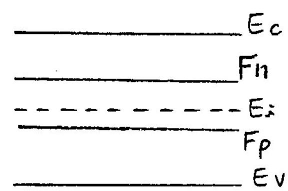
f) There is no a priori justification.

3) i) In the p-region: $p = N_a = 2\times10^{15}\ cm^{-3}$

$n = n_0 + \Delta n \simeq G_L \cdot \tau_n = 6\times10^{18} \times 10^{-6} = 6\times10^{12}\ cm^{-3}$

$\Rightarrow F_p = E_i - kT \ln \frac{2\times10^{15}}{10^{10}} = E_i - 0.20\ eV$

$F_n = E_i + kT \ln \frac{6\times10^{12}}{10^{10}} = E_i + 0.17\ eV$

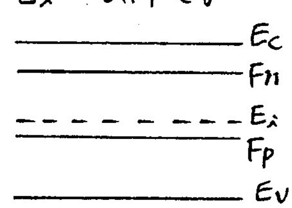


ii) in the n-region: $n = N_d = 4\times10^{16}\ cm^{-3}$

$p \simeq G_L \cdot \tau_p = 6\times10^{18} \times 10^{-6} = 6\times10^{12}\ cm^{-3}$

$\Rightarrow F_n = E_i + kT \ln \frac{4\times10^{16}}{10^{10}} = E_i + 0.40\ eV$

$F_p = E_i - kT \ln \frac{6\times10^{12}}{10^{10}} = E_i - 0.17\ eV$



4)

a) $I = qA n_i^2 \left(\frac{D_n}{L_n N_a} + \frac{D_p}{L_p N_d} \right) \left(e^{qV_a/kT} - 1 \right)$

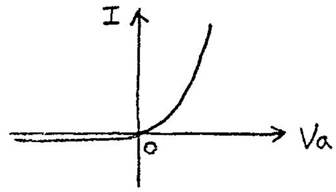
$= qA \left(\frac{D_n}{L_n} \cdot \frac{n_i^2}{N_a} + \frac{D_p}{L_p} \cdot \frac{n_i^2}{N_d} \right) \left(e^{qV_a/kT} - 1 \right)$

$= qA \left(\frac{D_n}{L_n} \cdot n_{po} + \frac{D_p}{L_p} \cdot p_{no} \right) \left(e^{qV_a/kT} - 1 \right)$

i) without illumination case:

if $T = 300K$, $V_a \gg 0.026$, $I \propto e^{V_a/0.026}$: forward bias

if " , $V_a \ll 0.026$, I = Constant. : reverse bias.

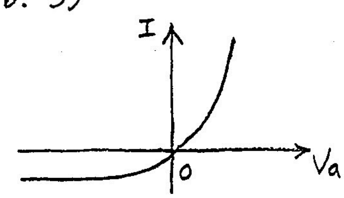


ii) with illumination case:

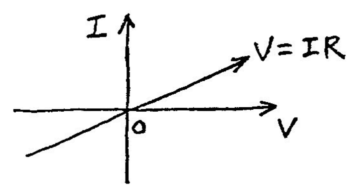
if it's in forward bias, the curve is same as above case.

if it's in reverse bias, the value is negative constant but it's different from the above case.

becase the minority carrier p_{no}, n_{po} is changed by illumination as prob. 3)



b) As T becomes very high, the intrinsic carrier concentration will become larger than the doping concentration, thus both the p & n material will become intrinsic and the diode will look like a simple resister.



Problem 2, midterm exam #1, spring 2007

5) a.) Approximately $V_{bi} = \frac{kT}{q} \ln \frac{N_a N_d}{n_i^2}$

This isn't perfect, because $p = 10^{18}\ cm^{-3}$ is technically degenerate.

$$V_{bi} = .026 \ln\left(\frac{10^{18}\ 10^{18}}{(1.1\times10^{10})^2}\right)$$

$$\boxed{V_{bi} \cong .95\ V}$$

b.) Consider a sample pn

p	n
10^{14}	10^{18}

$$X_p = \sqrt{\frac{2\epsilon}{q} V_{bi} \frac{N_d}{N_a(N_a+N_d)}}$$

$X_p = 3.5\ \mu m$

$$X_n = \sqrt{\frac{2\epsilon}{q} V_{bi} \frac{N_a}{N_d(N_a+N_d)}}$$

$X_n = 3.5\ Å$

So essentially all the depletion width is in the lightly doped region & the width in the heavily doped region is negligible.

$\therefore$ For $\underline{V_a = 0V}$

$$W = (x_{n+}) + (x_p) + (x_{p+})$$

$$\sim 0 \quad 2.5\mu m \quad \sim 0$$

$$\boxed{W \approx 2.5\mu m}$$

For $V_a = -5V$

$$W = (x_{n+}) + x_p + (x_{p+})$$

$$0 \quad 2.5\mu m \quad 0$$

$$\boxed{W \approx 2.5\mu m}$$

c) For same reasons, essentially all the voltage drop is across the $p = 10^{14} cm^{-3}$ region