Q1. Input file

[0.5]

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Title "np junction ~~from Fig. 6.7"~~ for Assignment 2, 480, 2011
T = 300.0;
mesh = 0.005 um;
Substrate = Si;
Terminals: cathode, anode;
LeftBoundary cathode ohmic;
0.05 um, [Ntype = 1.0E19 percm3] cathode;
0.1 um, [Ptype = 5.0E17 percm3] anode;
RightBoundary anode ohmic;
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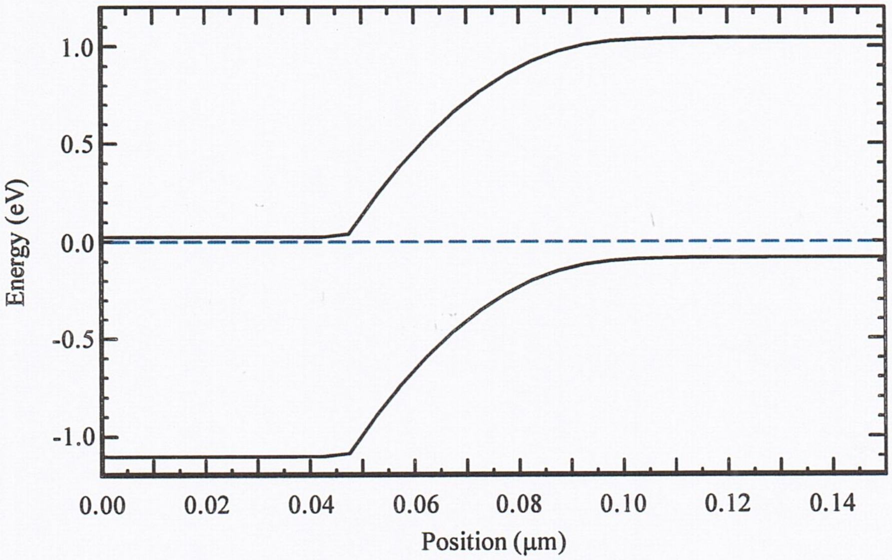
Q1. Band diagram

[0.5]



Q2. Manipulate E scale so ~~that~~ can read off $(E_c - E_F)$ on the n-side & $(E_F - E_v)$ on p-side.

[0.5] $E_c - E_F \big|_{n@NE} = \underline{2.3 \times 10^{-2}\ \text{eV}}$

[0.5] $E_F - E_V \big|_{p@NE} = \underline{8.1 \times 10^{-2}\ \text{eV}}$

Q3. [1] $n_0 = N_c \exp\left(\frac{E_F - E_C}{k_B T}\right) \ldots = 2.744\times10^{+19} \exp - \frac{2.3\times10^{-2}}{0.0259} = \underline{\underline{1.128\times10^{19}\ \mathrm{cm}^{-3}}}$

$N_{Veff} \doteq \Sigma$ 2 degenerate bands (see Fig. 2.9a)

$= 9.958\times10^{18} + 1.458\times10^{18}$ (Frensley's numbers)

$= 1.1416\times10^{19}\ \mathrm{cm}^{-3}$

[1] ∴ $p_0 = 1.1416\times10^{19} \exp - \frac{8.1\times10^{-2}}{0.0259} = \underline{\underline{5.004\times10^{17}\ \mathrm{cm}^{-3}}}$

Q4. In nQNR, charge neutrality: $-qn_0 + qp_0 + qN_D = 0$

Also : $n_0 p_0 = n_i^2$

∴ $n_0 = \frac{N_D + \sqrt{N_D^2 + 4n_i^2}}{2}$

[1] $N_D^2 \gg 4n_i^2$ ∴ $n_0 \approx \frac{N_D + N_D}{2} \approx N_D \approx \underline{\underline{1\times10^{19}\ \mathrm{cm}^{-3}}}$

[1] Similarly, $p_0 \approx N_A \approx \underline{\underline{5\times10^{17}\ \mathrm{cm}^{-3}}}$

Agreement for p_0 in Q3 & Q4 is OK.

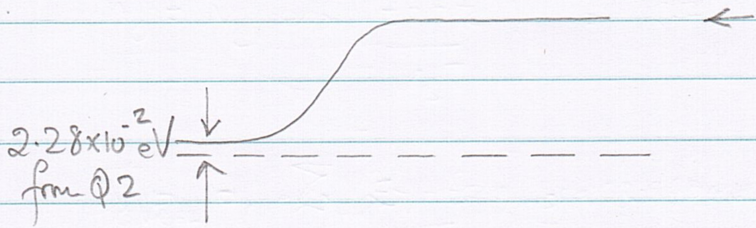
For n_0, the Q3 answer is slightly high.

This is probably because $(E_C - E_F)_{QNR}$ is $< 2k_BT$, ∴

[1] MB statistics is not strictly applicable, and FD stats should be used instead.

(Actually, FD stats gives $n_0 = 0.993\times10^{19}\ \mathrm{cm}^{-3}$)

Q5.



[1] $\therefore V_{bi} = 1.045 - 0.023 = \underline{\underline{1.022\ V}}$

For W, use the p-width as it is $\frac{N_D}{N_A}$ times longer than the

[1] n-width. (see Eqn. 6.16). $\rightarrow$ $0.11 - 0.05 = \underline{\underline{0.06\ \mu m}}$

Q6. $V_{bi} = V_{th} \ln \frac{N_A N_D}{n_i^2}$; $n_i = \left[N_c N_V e^{-E_g/k_B T}\right]^{\frac{1}{2}}$

$= 6.62\times10^{+9}\ cm^{-3}$ using Trensley's numbers

[1] $\therefore V_{bi} = 0.0259 \ln\left[\frac{5\times10^{17}\times10^{19}}{n_i^2}\right] = \underline{\underline{1.017V}}$

Agreement with answer from Q5 is OK.

$$W = \sqrt{\frac{2\varepsilon}{q} V_J \left(\frac{1}{N_A} + \frac{1}{N_D}\right)}$$

$$= \left[\frac{2\times11.8\times8.85\times10^{-14}\times1.017}{1.6\times10^{-15}}\left(\frac{1}{5\times10^{17}} + \frac{1}{10^{19}}\right)\right]^{1/2}$$

[1] $= \underline{\underline{52.8\ nm}}$

[½] Close enough because in Q5 it is difficult to estimate W from the graph.

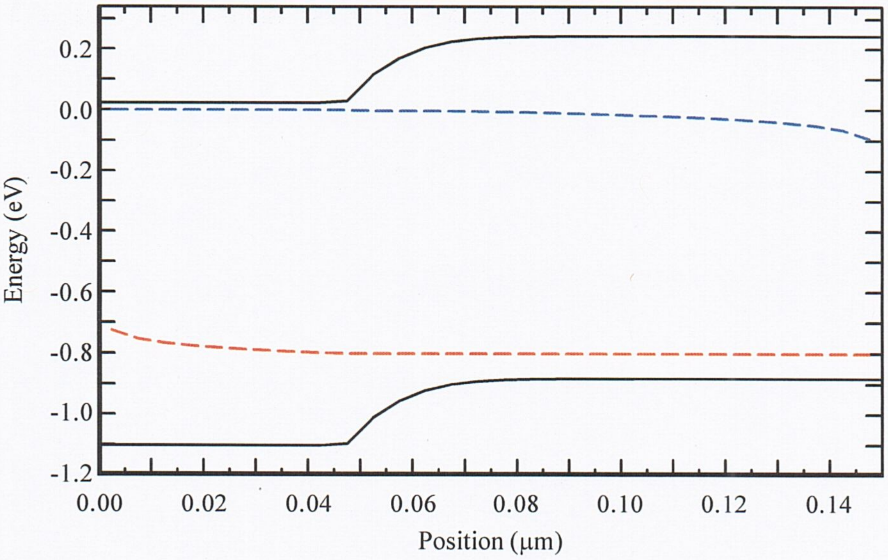
Q7. From an expanded version of the graph $V_J = 0.244 - 0.023$

$= \underline{\underline{0.221\,V}}$

[1]

From the graph $E_{Fn}(n@NR) = 0$, $E_{Fp}(p@NR) = -0.8\,eV$

[1] Bands are flat through SCR $\therefore (E_{Fn} - E_{Fp})_{SCR} = \underline{\underline{0.8\,eV}}$



Q8. [1] $V_J = V_{bi} - V_a = 1.022 - 0.8 = \underline{\underline{0.222V}}$

Agreement with Q7 is OK

[½] $(E_{Fn} - E_{Fp})\big|_{SCR} = qV_a = \underline{\underline{0.8eV}}$

Agreement with Q7 is OK.

Q9 for ideal diode: $|J_e| = q\, n_{op}\left(e^{-V_a/V_{th}} - 1\right) \cdot \frac{D_e}{L_e}$

For $p_{op} = 5\times10^{17}\ \mathrm{cm}^{-3}$, $n_{op} = \frac{n_i^2}{5\times10^{17}} = 87.6\ \mathrm{cm}^{-3}$

$\mu_e(5\times10^{17}) = 367\ \mathrm{cm}^2 V^{-1} s^{-1}$ from (5.30)

$\tau_e(5\times10^{17}) = 46.5\ \mathrm{ns}$ from (3.21)

$D_e = k_B T / q\mu_e = 9.5\ \mathrm{cm}^2 s^{-1}$

$L_e = (D_e \tau_e)^{1/2} = 6.57\times10^{-4}\ \mathrm{cm}$

[1] $\rightarrow \underline{J_e = 5.26\ A/\mathrm{cm}^2}$

[1] Bandprof gives $\underline{J_T = 394.6\ A/\mathrm{cm}^2}$

(Area is $1\times10^{-4}\ \mathrm{cm}^2$, $I = J\times A$)

[1] The discrepancy is large.
It is not due to neglecting J_h because $J_h \propto p_{on}$ and $p_{on} = \frac{n_i^2}{N_D} = 4.4\ \mathrm{cm}^{-3}$ i.e., $J_h \approx \frac{J_e}{20}$

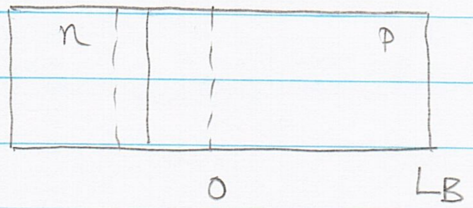
It is probably because Bandprof neglects recombination.

Q.10. From toolbox, $J_e = q D_e \frac{dn}{dx}$ in p-QNR

& $\frac{\partial n}{\partial t} = 0 = \frac{1}{q}\frac{dJ_e}{dx} + 0$ for no recombinati

$$\therefore \frac{d^2 n}{dx^2} = 0 \rightarrow \frac{dn}{dx} = C \rightarrow n = Cx + B$$

Relabel x-axis;



$n(0) = n_{op} e^{-V_a/V_{th}}$ Shockley

$n(L_B) = n_{op}$ OHMIC

$$\therefore B = n_{op} e^{-V_a/V_{th}}, \quad C = \frac{n_{op}}{L_B}\left(1 - e^{-V_a/V_{th}}\right).$$

$$J_e = q D \frac{dn}{dx} = q D_e \frac{n_{op}}{L_B}\left(1 - e^{-V_a/V_{th}}\right).$$

$$L_B = x_p - x_{dp} \; ; \quad x_{dp} = \frac{W \times N_D}{(N_D + N_A)} = \frac{52.8\times10^{-7} \times 10^{19}}{10^{19} + 5\times10^{17}} \text{ cm}$$

$$= 50 \text{ nm}$$

$$\therefore L_B = 100 - 50 = 50 \text{ nm}$$

$$\therefore |J_e| = 1.6\times10^{-19} \times 9.5 \times 87.6 \left(e^{0.8/0.0259}\right) / 50\times10^{-7} \quad \text{A cm}^{-2}$$

[1]

$$= \underline{\underline{691 \text{ A/cm}^2}}$$

[1] Reasonable agreement. Bandprof performs numerical simulation, i.e., does not make Depletion Approx which gives error here as L_B is small.