EE5340 Diagnostic
Fall 2011

1.) $x_E = 1\mu m$ $\quad N_{dE} = 6\cdot 10^{17}\ cm^{-3}$
$x_B = 0.8\ \mu m$ $\quad N_{aB} = 5\cdot 10^{16}\ cm^{-3}$

Diffusion constant for holes in the n type emitter is from the graph

$$D_{PE} = 9\ cm^2/s$$

Also for electrons in p type base

$$D_{nB} = 9\ cm^2/s.$$

$$\gamma = \frac{1}{1 + \frac{x_B N_{aB} \tilde{D}_{PE}}{x_E N_{dE} \tilde{D}_{nB}}}$$

$$\gamma = \frac{1}{1 + \frac{0.8\cdot 5\cdot 10^{16}\cdot 9}{1\cdot 6\cdot 10^{17}\cdot 9}}$$

$$\gamma = \frac{1}{1 + 6.666\cdot 10^{-2}}$$

$$\gamma = 0.9375$$

$$\alpha_T = 1 - \frac{x_B^2}{2\tau_n D_n}$$

$$= 1 - \frac{(0.8\cdot 10^{-4})^2\ cm^2}{2\cdot 4\cdot 10^{-9}\cdot 9\ cm^2}$$

$$\alpha_T = 0.9111$$

$$\alpha_F = \alpha_T \gamma = 0.85417$$

$$\beta_F = \frac{\alpha_F}{1-\alpha_F} = \underline{5.857}$$

Problem 1 Take into account depletion

$N_{dE} = 6 \cdot 10^{17}$ $N_{aB} = 5 \cdot 10^{16}$ $N_{dc} = 2 \cdot 10^{14} cm^{-3}$

$\tau_p = \tau_n = 4ns$

BE junction

$$V_{bi} = \phi_i = V_T \ln \frac{N_a N_d}{n_i^2}$$

$$= 0.025843 \ln \left[\frac{5 \cdot 10^{16} \cdot 6 \cdot 10^{17}}{(1.45 \cdot 10^{10})^2} \right]$$

$$\phi_i = 0.84227 \text{ V}$$

Emitter side $$X_n = \sqrt{\frac{2 \epsilon_s \phi_i}{q N_d^2 \left(\frac{1}{N_a} + \frac{1}{N_d} \right)}}$$

$$= \sqrt{\frac{2 \cdot 11.7 \cdot 8.854 \cdot 10^{-14} \cdot 0.84227}{1.602 \cdot 10^{-19} (6 \cdot 10^{-17})^2 \left(\frac{1}{5 \cdot 10^{16}} + \frac{1}{6 \cdot 10^{17}} \right)}}$$

$$X_n = 1.1817 \cdot 10^{-6} \text{ cm}$$

$$X_{nE} = 0.01817 \ \mu m$$

Base

$$X_p = \sqrt{\frac{2 \epsilon_s \phi_i}{q N_{aB}^2 \left(\frac{1}{N_a} + \frac{1}{N_d} \right)}}$$

$$X_{pB} = 0.14181 \ \mu m$$

BC junction

$$\phi_i = 0.025843 \ln \frac{2 \cdot 10^{14} \cdot 5 \cdot 10^{16}}{(1.45 \cdot 10^{10})^2}$$

$$= 0.63536 \text{ V}$$

$$X_{pC} = \sqrt{\frac{2 \epsilon_s \phi_i}{q N_a^2 \left(\frac{1}{N_a} + \frac{1}{N_d} \right)}} = 8.0916 \cdot 10^{-3} \ \mu m$$

$$X_E' = X_E - X_{nE}$$
$$= 1 - 0.01817$$
$$= 0.98183\ \mu m$$

$$X_B' = X_B - X_{pE} - X_{pc}$$
$$= 0.8 - 0.14181 - 8.0916 \cdot 10^{-3}$$
$$= 0.65010\ \mu m$$

$$\gamma = \frac{1}{1 + \frac{X_B' N_{aB} \tilde{D}_{pE}}{X_E' N_{dE} \tilde{D}_{nB}}}$$

$$= \frac{1}{1 + \frac{0.65010 \cdot 5 \cdot 10^{16} \cdot \cancel{9}}{0.98183 \cdot 6 \cdot 10^{17} \cdot \cancel{9}}}$$

$$\underline{\gamma = 0.94771}$$

$$\alpha_T = 1 - \frac{X_B^2}{2 \tau_n \tilde{D}_n}$$

$$= 1 - \frac{(0.65010 \cdot 10^{-4})^2}{2 \cdot 4 \cdot 10^{-9} \cdot 9}$$

$$\underline{\alpha_T = 0.94130}$$

$$\alpha_F = \alpha_T \gamma = 0.89208$$

$$\beta_F = \frac{\alpha_F}{1 - \alpha_F} = 8.266$$

2.)

$p = N_a = N_v e^{(\mathcal{E}_f - \mathcal{E}_v)/kT}$ Use N_v eqn.

$\mathcal{E}_f - \mathcal{E}_v = V_T \ln \frac{N_a}{N_v}$

$= 0.025843 \ln \frac{1.5 \cdot 10^{16}}{1.04 \cdot 10^{19}}$

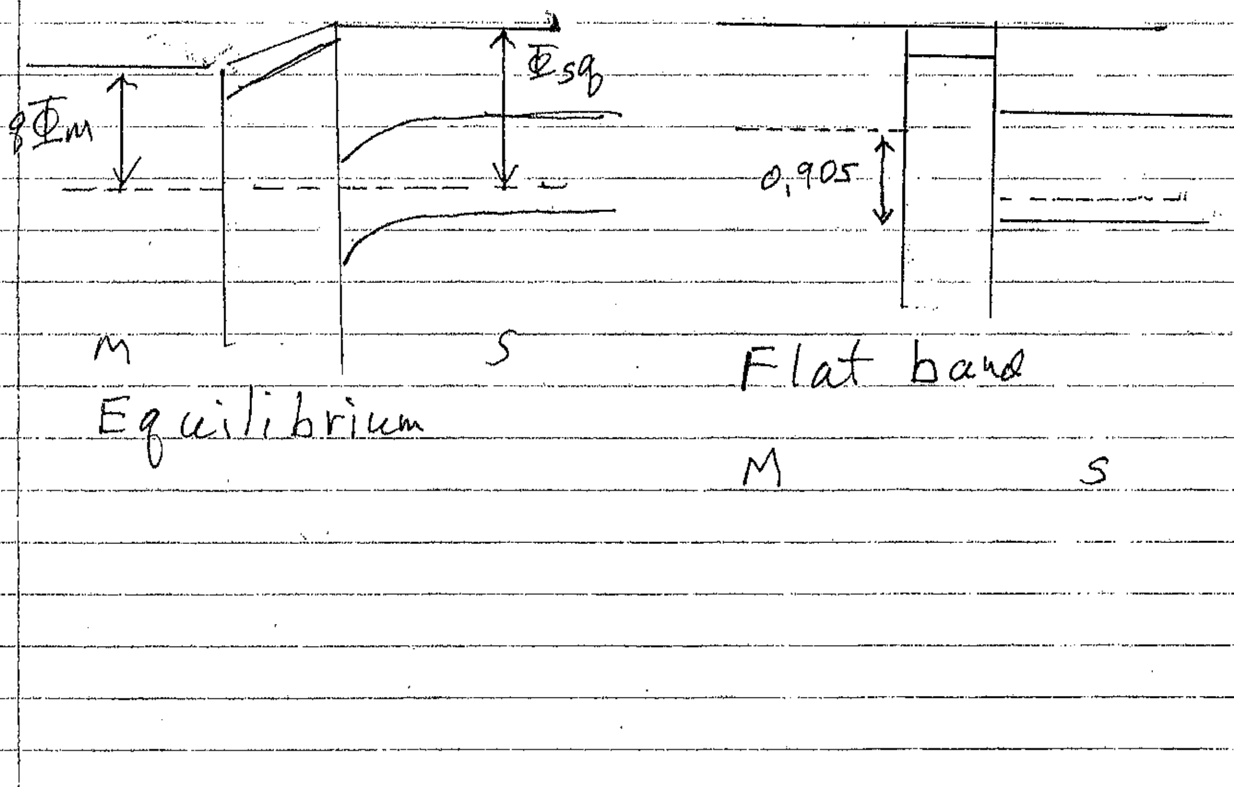
$\mathcal{E}_f - \mathcal{E}_v = 0.1691 \text{ eV}$

$q\Phi_s = q\chi_s + \mathcal{E}_g - (\mathcal{E}_f - \mathcal{E}_v)$

$= 4.05 + 1.124 - 0.1691$

$q\Phi_s = 5.005 \text{ eV}$

$V_{FB} = \Phi_M - \Phi_s = 4.1 - 5.005 = \underline{-0.905 \text{ eV}}$



2.) $N_a = 1.5\cdot 10^{16}\ cm^{-3}$ Use ni eqn

a) At equilibrium

$$p = N_a = n_i e^{(\mathcal{E}_i - \mathcal{E}_f)/kT}$$

$$\mathcal{E}_i - \mathcal{E}_f = V_T \ln \frac{N_a}{n_i}$$

$$= 0.025843 \ln\left(\frac{1.5\cdot 10^{16}}{1.45\cdot 10^{10}}\right)$$

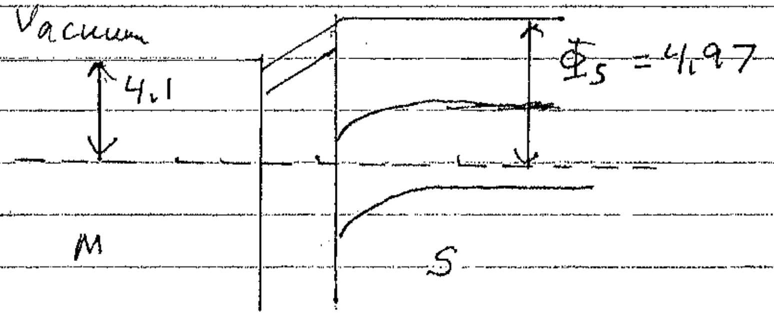
$$= 0.3579\ eV$$

$$q\Phi_s = q\chi_s + \mathcal{E}_g/_2 + (\mathcal{E}_i - \mathcal{E}_f)$$

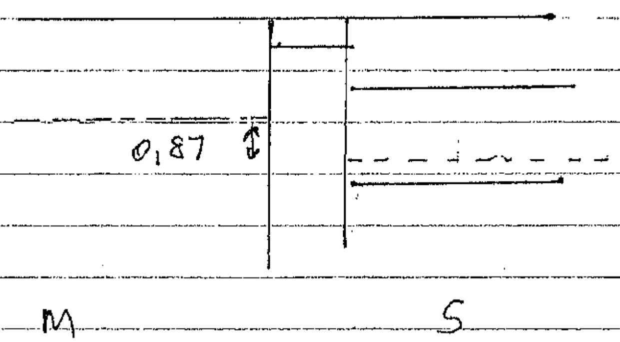
$$= 4.05 + 0.562 + 0.3579$$

$$q\Phi_s = 4.97\ V$$

$$V_{FB} = \Phi_M - \Phi_s = 4.1 - 4.97 = -0.870\ eV$$



Apply V_{FB}



3.) Poissons Equation

a.)

n-side $\frac{d^2\phi}{dx^2} = -\frac{dE}{dx} = -\frac{qN_d}{\epsilon_s}$ for the n-side

$$\int_x^{x_n} E(x)\,dx = +\int_x^{x_n} \frac{qN_d}{\epsilon_s}\,dx$$

$$E(x_n) - E(x) = -\frac{qN_d}{\epsilon_s}\, x \Big|_x^{x_n}$$

$E(x_n) = 0$

$$E(x) = -\frac{qN_d}{\epsilon_s}(x_n - x)$$

p-side
$$\int_0^{-x_p} E(x)\,dx = -\int_x^{-x_p} \frac{qN_a}{\epsilon_s}\,dx$$

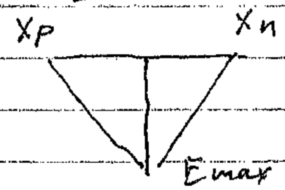
$$E(-x_p) - E(x) = -\frac{qN_a}{\epsilon_s}\, x \Big|_x^{-x_p}$$

$E(-x_p) = 0$

$$-E(x) = -\frac{qN_a}{\epsilon_s}(-x_p - x)$$

$$E(x) = -\frac{qN_a}{\epsilon_s}(x_p + x)$$

b.) $E_{max} = E(0)$



$$\phi_n = -\int_0^{x_n} E(x)\,dx$$

$$\phi_n = -\int_0^{x_n} \frac{qN_d}{\epsilon_s}(x_n - x)\,dx$$

$$= -\frac{qN_d}{\epsilon_s}\left(x x_n - \frac{x^2}{2}\right)\Big|_0^{x_n}$$

$$\phi_n = -\frac{qN_d}{2} x_n^2$$

$$\phi_p = -\int_0^{-X_p} \frac{qN_a}{\epsilon_s}(X_p + X)\,dx$$

$$= -\frac{qN_a}{\epsilon_s}\left(X_p + \frac{X}{2}\right)X\Big|_0^{-X_p}$$

$$= \frac{qN_a}{\epsilon_s}\frac{X_p^2}{2}$$

c.) $E_{max} = \cancel{E(0) = -\frac{qN_d}{\epsilon_s}X_n}$

$\cancel{0.5\,V/\mu m \cdot 10^4 \frac{\mu m}{cm} \cdot \frac{11.7 \cdot 8.854 \cdot 10^{-14}}{1.602 \cdot 10^{-19} \cdot 5 \cdot 10^{15}}} =$

$$X_n = \frac{\phi_n}{E_{max}} =$$

$$\phi_n = \frac{kT}{q}\ln\frac{N_d}{n_i} = 0.025843\,\ln\frac{5 \cdot 10^{15}}{1.45 \cdot 10^{10}}$$

$$\phi_n = 0.3295\ V$$

$$-\phi_p = \frac{kT}{q}\ln\frac{N_a}{n_i} \qquad N_a = 2 \cdot 10^{17}$$

$$\phi_p = 0.42585\ V$$

$$X_n = \frac{0.3295}{4000} = 0.8238\ \mu m$$

$$X_p = \frac{0.42585}{4000} = 1.0621\ \mu m$$

$$X_p + X_n = 1.8859\ \mu m.$$