3.1 Fall 2013 HW # 3 solution

Built in potential

$$\phi_j = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right) = (0.025V)\ln\left(\frac{10^{19}cm^{-3}\ 10^{18}cm^{-3}}{10^{20}\ cm^{-6}}\right)$$

$$\boxed{= 0.979V}$$

Depleation Width

$$W_{do} = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)\phi_j}$$

$$= \sqrt{\frac{2\cdot 11.7\cdot 8.85\times10^{-14}F/cm}{1.60\times10^{-19}C}\left(\frac{1}{10^{19}\ cm^{-2}}+\frac{1}{10^{18}cm^{-2}}\right)(0.979V)}$$

$$= 3.73\times10^{-6}\ cm$$

$$\boxed{= 37.3\ nm}$$ or equivilent

from example 3.2 :

$$X_n = \frac{W_{do}}{1+\frac{N_D}{N_A}} = \frac{37.3nm}{1+\frac{10^{18}}{10^{19}}} = \frac{37.3nm}{1.1} = \boxed{33.9\ nm}$$

$$X_p = \frac{W_{do}}{1+\frac{N_A}{N_D}} = \frac{37.3nm}{1+\frac{10^{19}}{10^{18}}} = \frac{37.3}{11} = \boxed{3.39\ nm}$$

$$E_{max} = \frac{2\phi_j}{W_{do}} = \frac{2(0.979V)}{3.73\times10^{-6}cm} = \boxed{5.2\times10^5\ V/cm}$$

$$= \frac{qN_aX_p}{\varepsilon_s} = \frac{qN_Dx_n}{\varepsilon_s} = 5.2\times10^5\ V/cm$$

3.2 Part A

$p_p \approx N_A = 10^{18} cm^{-3}$ $n_n \approx N_D = 10^{15} cm^{-3}$

$n_p = \frac{n_i^2}{p_p} = \frac{10^{20}}{10^{18}} = 100 cm^{-3}$ $p_n = \frac{n_i^2}{n_n} = \frac{10^{20}}{10^{15}} = 10^5 cm^{-3}$

3.12

$N_A(x) = N_0 \cdot \exp(-x/L) = p(x)$

$$j_p = \underbrace{q \mu_p p E}_{\text{Drift term}} - \underbrace{q D_p \frac{\partial p}{\partial x}}_{\text{Diffusion term}} = 0 \quad (*)$$

Because $\frac{\partial p}{\partial x} \neq 0$, there must be an electric field $E \neq 0$ to satisify the requirement that $j_p = 0$ in equlibrium.

What is $E(x)$?

$E(x) = \frac{V_T}{p(x)} \frac{\partial p}{\partial x}$, using equation (*) above and recalling that $\frac{D}{\mu} = \frac{KT}{q} = V_T$ for non-degenerate semiconductor.

$$\frac{\partial p}{\partial x} = \frac{\partial}{\partial x}\left(N_0 \exp\left(-x/L\right)\right) = \frac{-N_0}{L} \exp\left(-x/L\right)$$

$$E(x) = \frac{V_T}{N_0 \exp(-x/L)} \cdot \frac{-N_0}{L} \exp\left(-\frac{x}{L}\right) = \frac{-V_T}{L}$$

For this special Doping profile, the electric field is position independent. It is also independent of N_0

$$E(x) = \frac{-0.0250V}{1 \times 10^{-6} m} = 25000 \frac{V}{m} = \boxed{250 \frac{V}{cm}}$$

3.21

Because the diode current increases exponentially with bias voltage, it is in forward bias. Therefore

- $i_D = I_S\left[\exp\left(\frac{V_D}{nV_T}\right) - 1\right] \approx I_S \exp\left(\frac{V_D}{nV_T}\right)$

take $\log_{10}$ of Both sides

- $\log_{10}(i_D) = \log_{10}(I_S) + \frac{1}{\ln(10)} \cdot \frac{V_D}{nV_T}$

- Now, from the graph, we use the points $(0.2V, 10^{-9}A)$ and $(0.6V, 10^{-4}A)$ to determine the slope $\frac{1}{nV_T} \cdot \frac{1}{\ln(10)}$ and intercept $\log_{10}(I_S)$ of the log plot.

$$\text{slope} = \frac{-4-(-9)}{0.6V - 0.2V} = \frac{5}{0.4V} = 12.5$$

$$\text{intercept} = \log_{10}(I_S) = \log_{10}(I_1) - V_1 \cdot (\text{slope})$$
$$= -9 - 0.2(12.5)$$
$$= -11.5$$

Now

$$n = \frac{1}{\ln(10)} \cdot \frac{1}{\text{Slope} \cdot V_T} = \frac{1}{12.5 \cdot 0.025}(0.434) = \boxed{1.39}$$

$$I_S = 10^{\wedge}(-11.5) = \boxed{3.2\ pA}$$

3.24

$$I = I_s\left(\exp\left(\frac{V}{nV_T}\right)-1\right)$$

$$= 10^{-16}\left(\exp\left(\frac{0.675V}{0.0250V}\right)-1\right)$$

$$\boxed{= 53.2\,\mu A}$$

$$I = 10^{-16}\left(\exp\left(\frac{3*0.675V}{0.0250V}-1\right)\right) =$$

$$\boxed{= 1.51\times10^{19}\ A}$$

3,37

V_R 5V

V_D -10V

$\phi_j = 0.8$

$W_{d0} = 1\mu m$

$$W_d = W_{d0}\sqrt{1+\frac{V_R}{\phi_j}} \quad \text{eq. } 3.18$$

$$= 1\mu m\sqrt{1+\frac{5V}{0.8V}} =$$

$\boxed{= 2.7\,\mu m}$ for $V_R = 5V$

$V_d = -10V \Rightarrow V_R = 10\,V$

$$W_d = 1\mu\sqrt{1+\frac{10V}{0.8V}}$$

$\boxed{= 3.7\,\mu m}$ for $V_D = -V_R = -10V$

3.44

$$C_{jo} = \frac{\varepsilon_s}{W_{do}}$$

$$W_{do} = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)\phi_j}$$

$$\phi_j = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

$$\phi_j = 0.025 \ln\left(\frac{10^{18} \cdot 10^{15}}{10^{20}}\right) = 0.748\text{ V}$$

$$W_{do} = \sqrt{\frac{2 \cdot 11.7 \cdot 8.854\times10^{-14}\text{ F/cm}}{1.602\times10^{-19}\text{C}}\left(\frac{1}{10^{18}\text{cm}^{-3}} + \frac{1}{10^{15}\text{cm}^{-3}}\right)(0.748\text{V})}$$

$$W_{do} = 9.85\times10^{-5}\text{ cm}$$

$$C_{jo} = \frac{\varepsilon_s}{W_{jo}} = \frac{11.7 * 8.854\times10^{-14}\text{ F/cm}}{9.85\times10^{-5}\text{ cm}} = \boxed{1.05\times10^{-8}\text{ F/cm}^2}$$

for $V_R = 9\text{V}$

$$C_j = \frac{C_{jo} \cdot A}{\sqrt{1 + \frac{V_R}{\phi_j}}} = \frac{(1.05\times10^{-8}\text{ F/cm}^2)(0.02\text{ cm}^2)}{\sqrt{1 + \frac{9\text{V}}{0.748\text{V}}}}$$

$$\boxed{\begin{aligned} &= 5.83\times10^{-11}\text{ F} \\ &= 58.3\text{ pF}\end{aligned}}$$