Exercise Problems

3.1 Consider a MOS system with the following parameters:

$t_{ox} = 1.6$ nm

$\phi_{GC} = -1.04$ V

$N_A = 2.8 \cdot 10^{18}$ cm^{-3}

$Q_{ox} = q4.10^{10}$ C/cm^2

a. Determine the threshold voltage V_{T0} under zero bias at room temperature ($T = 300$ K). Note that $\varepsilon_{ox} = 3.97\varepsilon_0$ and $\varepsilon_{si} = 11.7\varepsilon_0$.

b. Determine the type (p-type or n-type) and amount of channel implant (N_I/cm^2) required to change the threshold voltage to 0.6 V.

3.2 Consider a diffusion area that has the dimensions 0.4 μm × 0.2 μm and the

H.W 3, EE 222 (solutions of 4th Edition)

3.1 Given:

$t_{ox} = 1.6nm$ $\qquad T = 300K$

$\phi_{GC} = -1.04V$ $\qquad \varepsilon_{ox} = 3.97 \times \varepsilon_0$

$N_A = 2.8 \times 10^{+18}\ cm^{-3}$ $\qquad \varepsilon_{si} = 11.7\,\varepsilon_0$

$Q_{ox} = q\,4 \times 10^{10}\ C/cm^2$ $\qquad \varepsilon_0 = 8.85 \times 10^{-12}\ F/m$

(a) $V_{T0} = \phi_{GC} - 2\phi_F - \frac{Q_{B0}}{C_{ox}} - \frac{Q_{ox}}{C_{ox}}$ — (1)

Find ϕ_F, C_{ox}, Q_{B0} and plug in those values in (1)

$\phi_F = \frac{KT}{q} \ln\left(\frac{n_i}{N_A}\right) = 0.026 \ln \frac{1.45 \times 10^{10}\ cm^{-3}}{2.8 \times 10^{18}\ cm^{-3}} = -0.493V$

$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.97 \times 8.85 \times 10^{-12}\ F/m}{1.6 \times 10^{-9}\ m} = 0.0219\ F/m^2$

$= 2.19 \times 10^{-6}\ F/cm^2$

$Q_{B0} = -\sqrt{2 q N_A \varepsilon_{si} |-2\phi_F|}$

$= -\sqrt{2 \times 1.6 \times 10^{-19} \times 2.8 \times 10^{-18} \times 11.7 \times 8.85 \times 10^{-12} \times |-2 \times -0.493|}$ (cm^{-3}; F/m)

$= -\sqrt{2 \times 1.6 \times 10^{-19} \times 2.8 \times 10^{+18} \times 11.7 \times 8.85 \times 10^{-14} \times 2 \times 0.493}$

$Q_{B0} = -9.56 \times 10^{-7}$

$\therefore V_{T0} = -1.04V - (2 \times -0.493V) - \left[\frac{-9.56 \times 10^{-7}}{2.19 \times 10^{-6}}\right] - \left[\frac{1.6 \times 10^{-19} \times 4 \times 10^{10}}{2.19 \times 10^{-6}}\right]$

$= -1.04 + 0.986 + 0.436 - 2.92 \times 10^{-3}$

$\boxed{V_{T0} = 0.379V}$

(b) n-type is the type. Amount of n-type implant needed is :

$$\Delta V = 0.6 - V_{TO} = 0.6 - 0.379 = 0.221V = \frac{qN_1}{C_{ox}}$$

$$0.221 = \frac{qN_1}{C_{ox}} \Rightarrow N_1 = \frac{0.221 \times C_{ox}}{q} = \frac{0.221 \times 2.19 \times 10^{-6}}{1.6 \times 10^{-19}}$$

$$\boxed{N_1 = 3.02 \times 10^{12}\ cm^{-2}}$$

gate is driving other fan-out gates.

(3.6) Consider a layout of an nMOS transistor shown in Fig. P3.6. The process parameters are

$N_D = 2.10^{20}\ \text{cm}^{-3}$

$N_A = 2.10^{20}\ \text{cm}^{-3}$

$X_j = 32$ nm

$L_D = 10$ nm

$t_{ox} = 1.6$ nm

$V_{T0} = 0.53$ V

Channel stop doping = 16.0 × (*p*-type substrate doping)

Find the effective drain parasitic capacitance when the drain node voltage changes from 1.2 to 0.6 V.

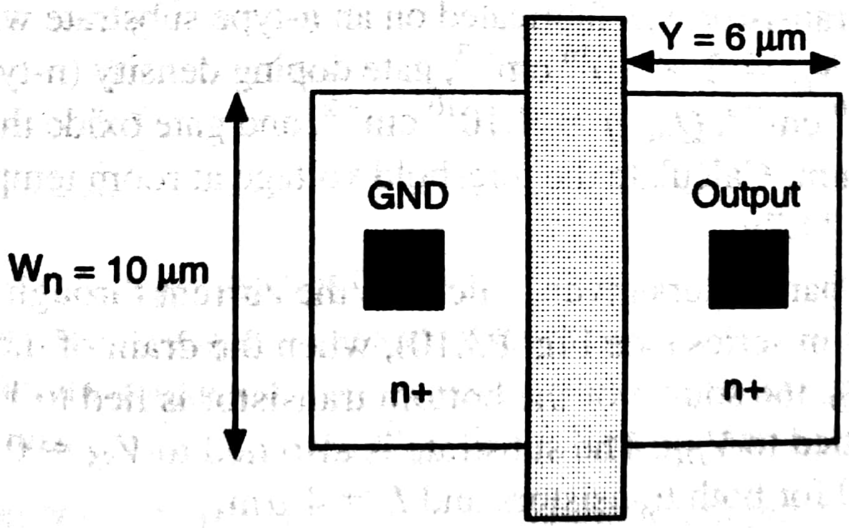

Figure P3.6

3.6 Given:

$N_D = 2\times10^{20}\ cm^{-3}$ $L_D = 10nm$

$N_A = 2\times10^{20}\ cm^{-3}$ $t_{ox} = 1.6nm$

$x_j = 32nm$ $V_{T0} = 0.53V$

Channel stop doping = $16.0\times$(p-type substrate doping) = N_A'

$$\phi_0 = \frac{KT}{q}\ln\frac{N_A\cdot N_D}{n_i^2} = 0.026\ln\left[\frac{2\times10^{20}cm^{-3}\times2\times10^{20}cm^{-3}}{(1.45\times10^{10}cm^{-3})^2}\right]$$

$$\phi_0 = 1.214\ [V]$$

$$\phi_{0sw} = \frac{KT}{q}\ln\left[\frac{N_A'\cdot N_D}{n_i^2}\right] = 0.026\times\ln\left[\frac{16\times2\times10^{20}\times2\times10^{20}}{(1.45\times10^{10})^2}\right]$$

$$= 1.286\ [V]$$

$$C_{jo} = \sqrt{\frac{\varepsilon_{si} \cdot q}{2}\left(\frac{N_A \cdot N_D}{N_A + N_D}\right)} \cdot \frac{1}{\sqrt{\phi_o}} \qquad \{\varepsilon_{si} = 11.7\varepsilon_o\}$$

$$= \sqrt{\frac{11.7 \times 8.85\times10^{-14} \times 1.6\times10^{-19} \times 2\times10^{20} \times 2\times10^{20}}{2\times(2\times10^{20} + 2\times10^{20})}} \cdot \frac{1}{\sqrt{1.214}}$$

$$= \frac{81405.65}{2.82\times10^{10}} \times 0.907$$

$$C_{jo} = 2.619\times10^{-6}\ [F/cm^2]$$

$$C_{josw} = \sqrt{\frac{\varepsilon_{si} \cdot q}{2}\left(\frac{N_A' \cdot N_D}{N_A' + N_D}\right)} \cdot \frac{1}{\sqrt{\phi_{osw}}}$$

$$= \sqrt{\frac{11.7\times8.85\times10^{-14} \times (32\times10^{20} \times 2\times10^{20})}{2\times(32\times10^{20} + 2\times10^{20})}} \cdot \frac{1}{\sqrt{1.286}}$$

$$= \frac{59334.05}{8.24\times10^{10}} \times 0.881$$

$$C_{josw} = 6.34\times10^{-7}\ [F/cm^2]$$

$$C_{sw} = X_j\, C_{josw} = 32\times10^{-7} \times 6.34\times10^{-7} = 2.02\times10^{-12}\ F/cm$$

$$= 2.02\ [pF/cm]$$

$$A = Y \times W = 6\times10 = 60\ [\mu m^2]$$

$$P = 2(Y+W) = 2(6+10) = 32\ [\mu m]$$

$$K_{eq} = 2\sqrt{\phi_0}\left(\frac{\sqrt{\phi_0 + 1.2} - \sqrt{\phi_0 + 0.6}}{1.2 - 0.6}\right)$$

$$= 2 \times \sqrt{1.214}\left[\frac{\sqrt{1.214 + 1.2} - \sqrt{1.214 + 0.6}}{0.6}\right]$$

$$= 2 \times 1.1018\left[\frac{1.553 - 1.346}{0.6}\right]$$

$$K_{eq} = 0.757$$

$$K'_{eq} = 2\sqrt{\phi_{osw}}\left[\frac{\sqrt{\phi_{osw} + 1.2} - \sqrt{\phi_{osw} + 0.6}}{1.2 - 0.6}\right]$$

$$= 2 \times \sqrt{1.286}\left[\frac{\sqrt{1.286 + 1.2} - \sqrt{1.286 + 0.6}}{0.6}\right]$$

$$= 2 \times 1.134\left[\frac{1.576 - 1.373}{0.6}\right]$$

$$K'_{eq} = 0.766$$

$$C_{drain} = K_{eq} \cdot C_{jo} \cdot A + K'_{eq} \cdot C_{jsw} \cdot P$$

$$= 0.757 \times 2.619 \times 10^{-6} \times 60 \times 10^{-8} + 0.766 \times 2.02 \times 10^{-12} \times 32 \times 10^{-4}$$

$$C_{drain} = 1.194 \times 10^{-12} F$$

$$C_{drain} = 1.194 pF$$

3.14 An enhancement-type nMOS transistor has the following parameters:

$V_{T0} = 0.48$ V

$\gamma = 0.52$ $V^{1/2}$

$\lambda = 0.05$ V^{-1}

$|2\phi_F| = 1.01$ V

$k' = 168$ $\mu A/V^2$

a. When the transistor is biased with $V_G = 0.6$ V, $V_D = 0.22$ V, $V_S = 0.2$ V, and $V_B = 0$ V, the drain current is $I_D = 24$ μA. Determine W/L.

b. Calculate I_D for $V_G = 1$ V, $V_D = 0.8$ V, $V_S = 0.4$ V, and $V_B = 0$ V.

c. If $\mu_n = 76.3$ cm^2/V·s and $C_g = C_{ox} \cdot W \cdot L = 1.0 \times 10^{-15}$ F, find W and L.

(a) $V_g = 0.6V,\ V_D = 0.22V,\ V_S = 0.2V$
$V_B = 0V,\ I_D = 24\mu A.$

3.14 Given:

$V_{TO} = 0.48V$

$\gamma = 0.52V^{1/2}$

$\lambda = 0.05V^{-1}$

$|2\phi_F| = 1.01V$

$K' = 168\mu A/V^2$

(a) $V_T(V_{SB}) = V_{TO} + \gamma\left(\sqrt{|2\phi_F| + V_{SB}} - \sqrt{|2\phi_F|}\right)$

$= 0.48 + 0.52\left(\sqrt{1.01 + 0.2} - \sqrt{1.01}\right)$

$= 0.53\ [V]$

$V_{DS} = 0.22 - 0.2 = 0.02$

$V_{GS} - V_T = (0.6 - 0.2) - 0.53 = -0.13$

Device in cut-off region??
Then how to find W/L if no current flow??

$V_{DS} > V_{GS} - V_{TH}$

$I_{D(sat)} = 24\mu A = \frac{K'}{2}\frac{W}{L}(V_{GS} - V_t)^2(1 + \lambda V_{DS})$

$\therefore \frac{W}{L} = \frac{2 \cdot I_{D(sat)}}{(V_{GS} - V_t)^2(1 + \lambda V_{DS}) \cdot K'}$

$\frac{W}{L} = \frac{2 \times 24 \times 10^{-6}}{(0.13)^2 \times (1 + 0.05 \times 0.02) \times 168 \times 10^{-6}}$

$= \frac{48 \times 10^{-6}}{0.0169 \times (1.001) \times 168 \times 10^{-6}} = 16.889 \approx 17$

(b). $V_T(V_{SB}) = V_{T0} + \gamma\left(\sqrt{|2\phi_F| + V_{SB}} - \sqrt{|2\phi_F|}\right)$

$= 0.48 + 0.52\left(\sqrt{1.01 + 0.4} - \sqrt{1.01}\right)$

$= 0.48 + 0.52\left(\sqrt{1.41} - \sqrt{1.01}\right)$

$= 0.574\,V$

$V_{DS} = 0.4V$, $V_{GS} - V_T = 0.6 - 0.574 = 0.025V$

$V_{DS} > V_{GS} - V_T$

⇒ Device is in saturation region.

$W/L = ??$ to calculate I_D.

$I_D = \frac{K'}{2}\frac{W}{L}(V_{GS} - V_{TH})^2(1+\lambda V_{DS}) = \frac{168}{2} \times 17 \times (0.6-0.574)^2(1+0.05\times0.4) = 0.98A$

(c) $\mu_n = 76.3\,cm^2/V.s$ & $C_g = C_{ox}.W.L = 1\times10^{-15}$ F

$C_{ox} = \frac{K'}{\mu_n} = \frac{168\times10^{-6}}{76.3} = 2.2\times10^{-6}$ F/cm²

$W.L = \frac{C_g}{C_{ox}} = \frac{10^{-15}}{2.2\times10^{-6}} = 4.54\times10^{-10}$

$\frac{W}{L} = ?$ (need to find it from part a).

$\frac{W}{L} = 17$

$17L^2 = 4.54\times10^{-10}$

$L = 5.16\times10^{-6}$

$W = 8.78\times10^{-5}$