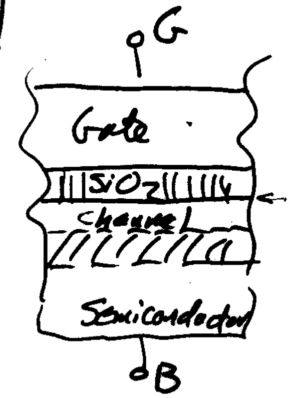
THRESHOLD VOLTAGE OF MOS TRANSISTOR

V_T = Work function between Gate and channel + Surface charge between the oxide and bulk silicon + Potential to change the surface potential to strong inversion

$$V_T = \underbrace{\left[\phi_{GC}\right] + \left[-\frac{Q_{ox}}{C_{ox}}\right]}_{V_{FB} = \phi_{GC} - \frac{Q_{ox}}{C_{ox}}} + \left[-2\phi_F - \frac{Q_B}{C_{ox}}\right]$$



Bottom line:

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

Definitions:

ϕ_{GC} is the work function between the gate & channel

Q_{ox} is the charge in oxide layer

C_{ox} is the capacitance between the gate and semiconductor

ϕ_F is the Fermi potential

$$\phi_{FP} = \frac{kT}{q}\ln\left(\frac{n_i}{p}\right)$$

$$\phi_{FN} = \frac{kT}{q}\ln\left(\frac{n}{n_i}\right)$$

n_i = intrinsic concentration

Q_B is the induced depletion layer charge

$Q_B = ?$

$Q_B = q N_A X_d$ where X_d = depletion region width

Assume a step pn junction,

$$X_d = \sqrt{\frac{2\epsilon_{si}|\phi_s - \phi_F|}{q N_A}}$$

$$Q_B = -\sqrt{2 q N_A \epsilon_{si} |\phi_s - \phi_F|}$$

Note: ϕ_s is a function of V_{SB}.

Let $V_{SB} = 0 \longrightarrow Q_{B0}$

When $V_{SB} = 0$, the depletion region consists of a fixed negative charge written as $(\phi_s = -\phi_F)$

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

$$\therefore V_T = V_{FB} - 2\phi_F - \frac{Q_B}{C_{ox}} + \frac{Q_{B0}}{C_{ox}} - \frac{Q_{B0}}{C_{ox}}$$

$$V_T = \underbrace{\left[\phi_{GC} - \frac{Q_{ox}}{C_{ox}} - \frac{Q_{B0}}{C_{ox}} - 2\phi_F\right]}_{\text{Independent of } V_{BS}} - \left(\frac{Q_B - Q_{B0}}{C_{ox}}\right)$$

$$V_T = V_{T0} - \left(\frac{Q_B - Q_{B0}}{C_{ox}}\right) = V_{T0} + \sqrt{2q\epsilon_{si}N_A}$$

$$= V_{T0} + \sqrt{2q\epsilon_{si}N_A}\left[\sqrt{|-2\phi_F| + V_{SB}} - \sqrt{|-2\phi_F|}\right]$$

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

Fwd. bias

Ex. 2.3

"Bulk threshold parameter"

Determine C_{ox} and γ if $t_{ox} = 22\,\text{Å}$ and $N_A = 3\times10^{17}\,\text{cm}^{-3}$

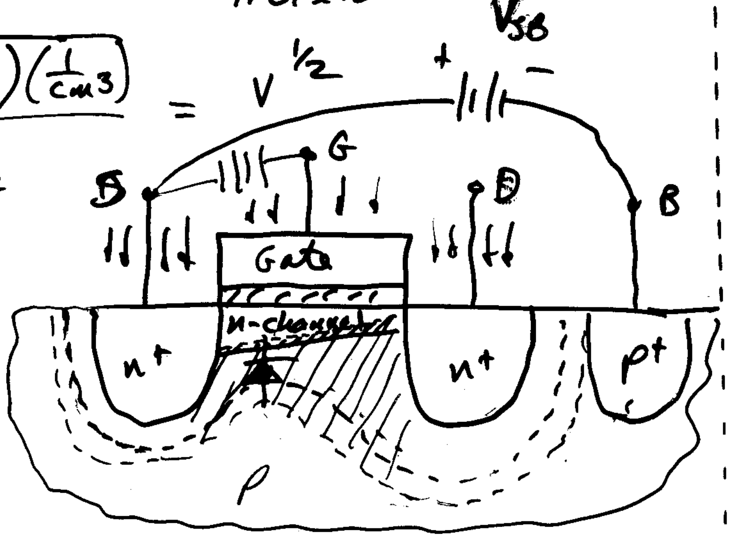
$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$, $\epsilon_{ox} = 4\epsilon_0 = 4(8.85\times10^{-14}\,\text{F/cm})$

$$C_{ox} = \frac{4(8.85\times10^{-14}\,\text{F/cm})}{22\times10^{-8}\,\text{cm}} = 1.61\times10^{-6}\,\frac{\text{F}}{\text{cm}^2}$$

$$\gamma = \frac{\sqrt{2q\epsilon_{si}N_A}}{C_{ox}} = \frac{\sqrt{2\cdot(1.6\times10^{-19})(11.7)(8.85\times10^{-14})(3\times10^{17})}}{1.61\times10^{-6}}$$

$$\frac{\sqrt{(F\cdot V)\left(\frac{F}{cm}\right)\left(\frac{1}{cm^3}\right)}}{\frac{F}{cm^2}} = V^{1/2}$$

$$\gamma = 0.196\ V^{1/2}$$



Ex. 2.4

Calculate V_{TO} for an NMOS assuming substrate doping of $N_A = 3\times10^{17}\,cm^{-3}$, gate doping of $N_D = 10^{20}\,cm^{-3}$, gate $t_{ox} = 22\,Å$ and there are $2\times10^{10}\,cm^{-2}$ positive charged ions per area at the oxide-semiconductor interface

$$V_{TO} = \phi_{GS} - 2\phi_F - \frac{Q_{bo}}{C_{ox}} - \frac{Q_{ox}}{C_{ox}} \quad (V_{SB}=0)$$

$$\phi_c = \phi_{Fp} = \frac{kT}{q}\ln\left(\frac{n_i}{N_A}\right) = 0.026\ln\left(\frac{1.45\times10^{10}}{3\times10^{17}}\right) = -0.438V$$

Assume the poly gate has the doping of the source/drain because of implantation of those areas,

$$\phi_G(\text{gate}) = 0.026\ln\left(\frac{10^{20}}{1.45\times10^{10}}\right) = 0.589\,V$$

For n doping, $\phi_{GS} < 0$:

$$\phi_{GC} = -(\phi_G - \phi_c) = -(0.589-(-.438)) = -1.027\,V$$

$$\epsilon_{ox} = 4\epsilon_0 = 3.54\times10^{-13}\,F/cm^2$$

$$C_{ox} = 1.6\ \mu F/cm^2$$

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

$$Q_{BO} = -\sqrt{2(1.6\times10^{-19})(11.7)(8.85\times10^{-14})(3\times10^{+17})\,2(0.435)}$$

$$= -2.95\times10^{-7}\ \frac{\text{coulombs}}{\text{cm}^2}$$

$$\frac{Q_{BO}}{C_{ox}} = \frac{-2.95\times10^{-7}}{1.61\times10^{-6}} = -0.183\text{V}$$

$$\frac{Q_{ox}}{C_{ox}} = \frac{2\cdot10^{10}(1.6\times10^{-19})}{1.61\times10^{-6}} = 0.002\text{V}$$

$$V_{TO} = \phi_{GC} - 2\phi_F - \frac{Q_{BO}}{C_{ox}} - \frac{Q_{ox}}{C_{ox}} = -1.027 + 0.876 + 0.183 - 0.002$$

$$\underline{\underline{V_{TO} = 0.03\text{V}}}$$

What about "real" thresholds?