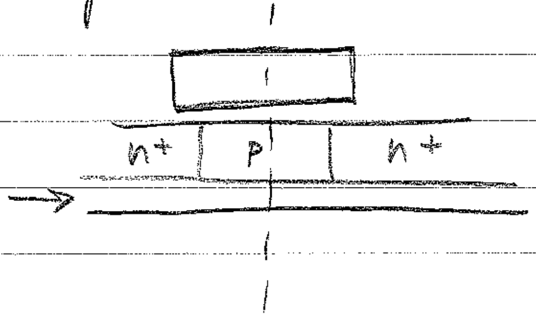
Fully depleted SOI:



Need a reference: use E_i ($n=p=n_i$)

$$\psi_i = \frac{1}{q}(E_f - E_i) \qquad \rho = q\left[N_d^+ - N_a^- + p - n\right]$$
$$= q\left(N_d^+ - N_a^- + n_i\left(e^{-\frac{q\psi_i}{kT}} - e^{\frac{q\psi_i}{kT}}\right)\right]$$

$$\frac{d^2\psi_i}{dx^2} = -\frac{d\mathcal{E}}{dx} = -\frac{\rho}{K_s\epsilon_0} = \frac{q}{K_s\epsilon_0}\left[(N_a^- - N_d^+) + n_i\left(e^{\frac{q\psi_i}{kT}} - e^{-\frac{q\psi_i}{kT}}\right)\right]$$

$$\times \frac{d\psi_i}{dx}, \quad \int_{0 \leftarrow \psi_i(0),\ \left.\frac{d\psi_i}{dx}\right|_0}^{x \leftarrow \psi_i = \psi_i(x),\ \left.\frac{d\psi_i}{dx}\right|_{x}} \Rightarrow$$

$$\int_{\left.\frac{d\psi_i}{dx}\right|_0}^{d\psi_i/dx} \left(\frac{d\psi}{dx}\right) d\left(\frac{d\psi}{dx}\right) = \frac{q}{K_s\epsilon_0}\int_{\psi_i(0)}^{\psi_i}\left[\underbrace{(N_a^- - N_d^+)}_{N_a} + n_i\left(e^{\frac{q\psi_i}{kT}} - e^{-q\psi_i/kT}\right)\right]d\psi$$

$$\mathcal{E}^2(x) - \mathcal{E}^2(0) = \frac{q}{K_s\epsilon_0}\left\{N_a(\psi_i - \psi_i(0)) + \frac{kTn_i}{q}\left[\left(e^{q\psi_i/kT} - e^{q\psi_i(0)/kT}\right) + \left(e^{-\psi_i/kT} - e^{q\psi_i(0)/kT}\right)\right]\right\}$$

Fully depleted SOI

Simple picture (sheet charge approximation)

$$\psi_i = \frac{1}{q}(E_f - E_i)$$

Assume depleted weak/strong inversion near front channel)

depletion only near back channel

$$\psi_i(0) \equiv \psi_I \cong 0.5\,eV \Rightarrow n_s = n_i e^{q\psi_I/kT} = 2.4 \times 10^{18}\,cm^{-3}$$

V_T ? Q_i small, $\psi_i(0) = \psi_I$, $\underbrace{Q_d' = q\int_0^{x_s}(N_a - N_d)\,dx}_{\text{Constant}}$

$$= -q\int_0^{x_s} N(x)\,dx$$

$$Q_{g1}' + Q_d' + Q_{g2}' = 0$$

$$\frac{-Q_{g2}'}{C_{ox2}'}$$

$$V_{g1g2} = \underset{\underset{\frac{Q_{g1}'}{C_{ox1}'}}{\uparrow}}{V_{ox1}} + \underset{\underset{-\frac{Q_{g2}'}{C_s'} + \frac{q}{K_s\varepsilon_0}\int_0^{x_s} x N(x)\,dx}{\uparrow}}{V_s} + V_{ox2}$$

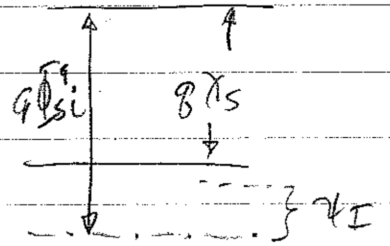
$$Q_{g2} = -Q_{g1}' - Q_d'$$

$$\underbrace{\frac{q}{K_s\varepsilon_0}\int_0^{x_s} x N(x)\,dx}_{-\frac{Q_d'}{C_s'}\underbrace{\left(\frac{\int_0^{x_s} x N(x)\,dx}{x_s\int_0^{x_s} N(x)\,dx}\right)}_{\bar{x}}}$$

$$V_{g1g2} = \frac{-Q_{g2}' - Q_d'}{C_{ox1}} - \frac{Q_{g2}'}{C_s'} - \frac{Q_d'}{C_s'}\bar{x} - \frac{Q_{g2}'}{C_{ox}'}$$

$$= -Q_{g2}'\left(\frac{1}{C_{ox1}} + \frac{1}{C_s'} + \frac{1}{C_{ox2}}\right) - Q_d'\left(\frac{1}{C_{ox1}'} + \frac{\bar{x}}{x_s}\frac{1}{C_s'}\right)$$

$$V_T = V_{g1s}(EOSI) = \Phi_{M1SI} + V_{ox1} = \Phi_{M1} - (\Phi_{si} - \psi_I) + \frac{Q'_{g1}}{C'_{ox1}}$$



$$Q'_{g1} = -(Q'_d + Q'_{g2})$$

$$V_{g2s} = \Phi_{M2SI} - V_s - V_{ox2}$$

$$V_s = -\frac{Q_{g2}}{C_s'} + \frac{q}{K_s \epsilon_0}\int_0^{x_s} x N(x)\,dx$$

$$= -\frac{Q_{g2}}{C_s'} - \frac{Q_d'}{C_s'}\frac{\bar{x}}{x_s} \leftarrow \frac{\int_0^{x_s} x N(x)\,dx}{\int_0^{x_s} N(x)\,dx}$$

$$V_{ox2} = -\frac{Q'_{g2}}{C'_{ox2}}$$

$$V_{g2s} = \Phi_{M2SI} + Q_{g2}\left(\frac{1}{C_s'} + \frac{1}{C'_{ox2}}\right) + \frac{Q_d'}{C_s'}\frac{\bar{x}}{x_s}$$

$$Q_{g2} = \frac{V_{g2s} - \Phi_{M2SI} - \frac{Q_d'}{C_s'}\frac{\bar{x}}{x_s}}{\left(\frac{1}{C_s'} + \frac{1}{C'_{ox2}}\right)} = \frac{C_s' C'_{ox2}}{C_s' + C'_{ox2}}\left[V_{g2s} - \Phi_{M2SI} - \frac{Q_d'}{C_s'}\frac{\bar{x}}{x_s}\right]$$

$$V_T = \Phi_{M1SI} - \frac{Q_d' + Q'_{g2}}{C'_{ox1}}$$

$$= \Phi_{M1SI} - \overset{1/3}{\left[\frac{C_s' C'_{ox2}}{(C_s' + C'_{ox2})C'_{ox1}}\right]}(V_{g2s} - \Phi_{M2SI})$$

$$- \frac{Q_d'}{C'_{ox1}}\left[1 - \underbrace{\frac{C_s' C'_{ox2}}{(C_s' + C'_{ox2})}\frac{1}{C_s'}}_{2/3}\overset{1/2}{\left(\frac{\bar{x}}{x_s}\right)}\right]$$

$$C'_{ox1} = C'_{ox2} = 2C_s'$$

$$= \frac{4 \times 8.854\times10^{-14}\,F/cm}{10^{-7}\,cm}$$

$$= 3.54\times10^{-6}\frac{F}{cm^2}$$

Examples $t_{ox1} = t_{ox2} = 1nm \quad x_s = 6nm$

$\Phi_{M1SI} = \Phi_{M2SI} = 0.5V \leftarrow$ midgap

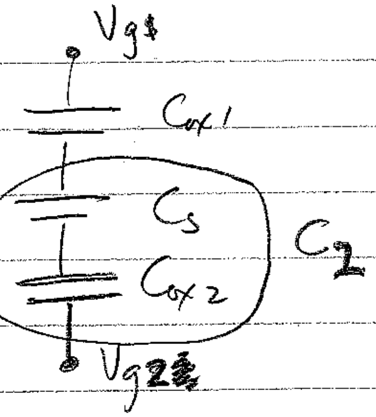
$N_a = 10^{19}\,cm^{-3}$

$V_{g2s} = 0$

$Q_d' = 9.6\times10^{-7}\frac{C}{cm^2}$

$$V_T = \overset{0.66V}{\frac{4}{3}(0.5)} + \overset{0.18}{\frac{9.6}{35.4}\left[1 - 1/3\right]} = 0.84$$

$$\frac{dV_T}{d\underset{\uparrow\atop (V_{g2s}-\Phi_{M2SI})}{V_{g2s}}} = \frac{C_s' C_{ox2}'}{(C_s'+C_{ox2}')C_{ox1}'} = \frac{C_2}{C_{ox1}'}$$



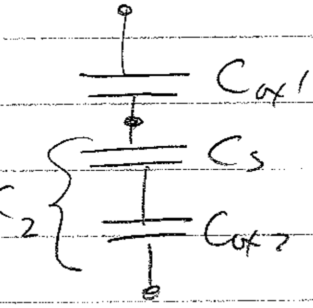
$$\frac{dV_T}{dQ_d'} = \frac{1}{C_{ox1}'}\left[1 - \frac{C_2'}{C_s'}\frac{\bar{x}}{x_s}\right]$$

Add Q_i : $Q_i = \underset{\uparrow}{C_{ox1}'}(V_{g1s} - V_T)$ ideal

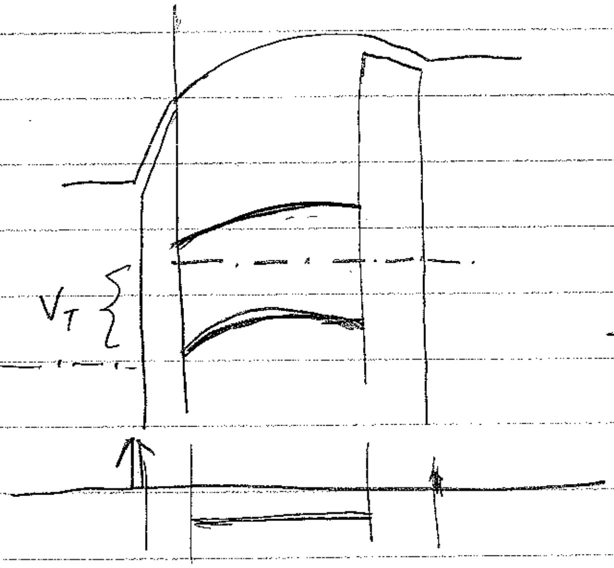
reality ⇒ $\frac{C_{ox1} C_{inv}}{C_{ox1}+C_{inv}}$

Subthreshold slope

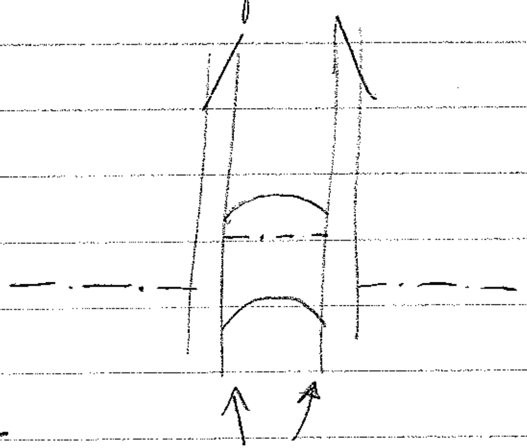
$$\eta = 1 + \frac{C_2}{C_{ox1}}$$



SCE



Dual gate



two sets of inversion charge