Metal – Oxide – Si (MOS) Cap — HW #6 Soln

1. Metal $\Rightarrow$ Polysi doped so $(E_f - E_c)_{Bulk} = 0.05\,eV$ $\therefore$ n+

$t_{ox} = X_{ox} = 50\,\text{Å} = 50\times10^{-8}\,cm$

No significant oxide charges / p-type Si w/ $N_a = 5\times10^{17}$

$$C_{ox}' = \frac{K_{ox}\epsilon_0}{t_{ox}} = \frac{(3.9)(8.854\times10^{-14})}{50\times10^{-8}} = 6.91\times10^{-7}\,\frac{F}{cm^2}$$

$\Phi_m = \chi_s - .05 = 4.0\,V$

$\phi_s = \chi_s + E_g - (E_f - E_v)_{bulk}$

$$E_F - E_V = kT\ln\left(\frac{N_v}{p_0}\right) = .026\ln\left(\frac{1.04\times10^{19}}{5\times10^{17}}\right) = .079\,eV$$

$\Phi_s = 4.05 + 1.12 - .08 = 5.09V$

$\Phi_{ms} = 4 - 5.09 = \underline{-1.09} = V_{FB}$ (No oxide charges)

$$V_T = \Phi_{ms} - 2\phi_F - \frac{Q_B'}{C_{ox}'} - \frac{Q_{ss}}{C_{ox}'}^{\approx 0}$$

$$\phi_F = -\frac{kT}{q}\ln\frac{N_a}{n_i} = -.026\ln\left(\frac{5\times10^{17}}{1.5\times10^{10}}\right) = -.45\quad V$$

$$Q_B' = Q_{dmax}' = -\sqrt{2K_s\epsilon_0 qN_a|2\phi_F|} = -3.881\times10^{-7}\,\frac{C}{cm^2}$$

$$V_T = -1.09 - 2(-.45) - \frac{(-3.88\times10^{-7})}{6.91\times10^{-7}} = \underline{.3716\,V}$$

a) $V_{gb} = -1V$ $\qquad V_{FB} < V_{gb} < V_T \Rightarrow$ depletion

$$V_{gb} - \phi_{ms} = V_{ox} + V_s \qquad V_{ox} = -\frac{Q_B'}{C_{ox}'} \quad eq\ (11)$$

$$-1 + 1.09 = \frac{\sqrt{2qK_s\epsilon_0 N_a V_s}}{C_{ox}'} + V_s$$

+ since $\sqrt{V_s} > 0$

$$0.09 = 0.59\sqrt{V_s} + V_s \Rightarrow \sqrt{V_s} = \frac{-0.59 \pm \sqrt{(0.59)^2 + 4(0.09)}}{2} = 0.126$$

$\phi_s = V_s = 0.016\,V$ $\qquad Q_g = C_{ox}V_{ox} = 4.64\times10^{-8}\,C/cm^2$

$V_{ox} = 0.59\sqrt{V_s} = 0.07\,V$ $\qquad C_d' = \frac{K_s\epsilon_0}{x_d} = 1.79\times10^{-6}\,C/cm^2$ at high f

$x_d = \frac{-Q_s}{qN_a} = \frac{Q_g}{qN_a} = 5.8\times10^{-7}\,cm$ $\qquad C = \frac{C_{ox}'C_d'}{C_{ox}'+C_d'} = 5.0\times10^{-7}\,C/cm^2$ low F

1b) $V_{gb} = 0.0\,V$ $\qquad V_{FB} < V_{gb} < V_T \Rightarrow$ depletion

$$V_{gb} - \phi_{ms} = V_{ox} + V_s$$

$$1.09 = \frac{\sqrt{2K_s\epsilon_0 q N_a V_s}}{C_{ox}'} + V_s = 0.59\sqrt{V_s} + V_s$$

$$V_s + 0.59\sqrt{V_s} - 1.09 = 0$$

$$\sqrt{V_s} = 0.79 \Rightarrow \underline{V_s = 0.62} = \phi_s$$

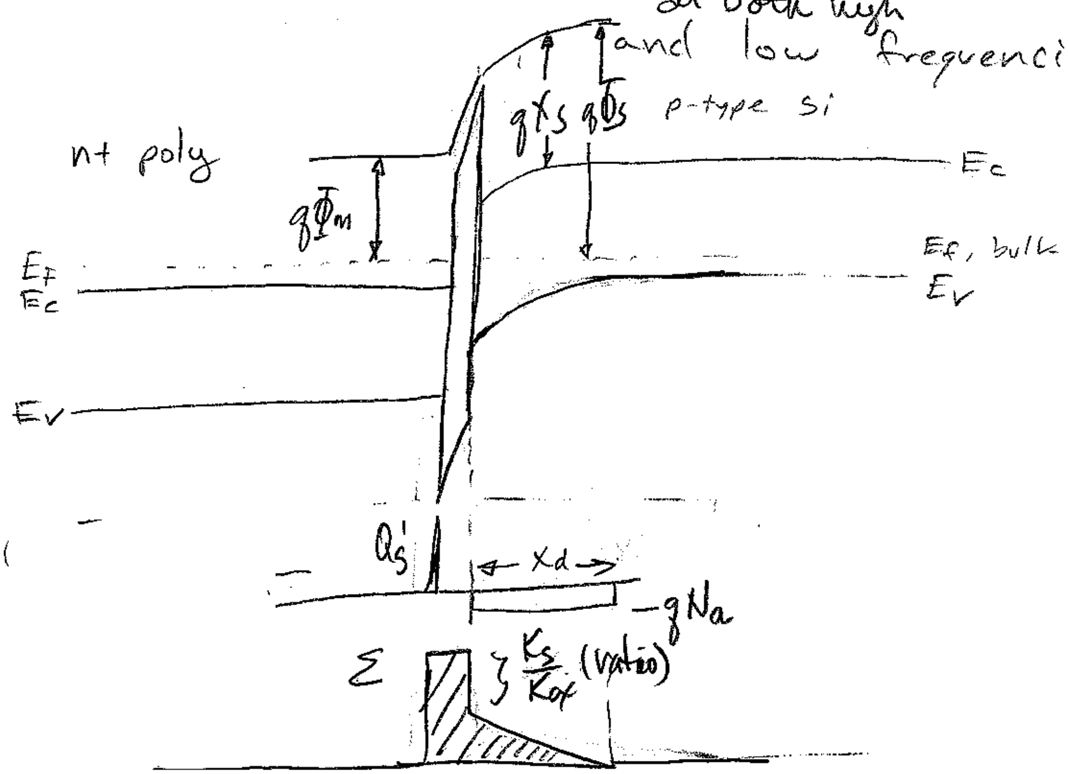
$$V_{ox} = 0.59\sqrt{V_s} = 0.47$$

$$Q_G' = -Q_d' = C_{ox}' V_{ox} = 3.25\times10^{-7}\,\frac{C}{cm^2}$$

$$C_s' = \frac{K_s\epsilon_0}{X_d} = \frac{K_s\epsilon_0}{Q_d/qN_a} = \frac{(11.8)(8.854\times10^{-14})}{\frac{3.25\times10^{-7}}{(1.6\times10^{-19})(5\times10^{17})}} = 2.57\times10^{-7}\,\frac{F}{cm^2}$$

$$C_{mos}' = C_{ox}' \| C_s' = \frac{C_s' C_{ox}'}{C_s' + C_{ox}'} = \frac{(2.57\times10^{-8})(6.906\times10^{-7})}{C_s' + C_{ox}'} = 1.87\times10^{-7}\,\frac{F}{cm^2}$$

at both high and low frequencies (depletion region is modulated rapidly)



1c) $V_{gb} = 2V$ $\qquad$ $V_{gb} > V_T \Rightarrow$ Inversion

$$V_s = \phi_s \cong 2|\phi_F| = 2(.4504) = .9008\ V$$

$$V_{gb} - \phi_{ms} = V_{ox} + V_s$$

$$2 + 1.0911 = V_{ox} + .9008 \Rightarrow V_{ox} = 2.1823\ V$$

$$V_{ox} = -\frac{Q_s'}{C_{ox}'} \Rightarrow Q_s' = -2.1823(6.906\times10^{-7}) = -1.507\times10^{-6}\ \frac{C}{cm^2}$$

$Q_m' = -Q_s'$ (since no oxide charge) $\Rightarrow$

$$Q_m' = Q_g' = 1.51\times10^{-6}\ \frac{C}{cm^2}$$

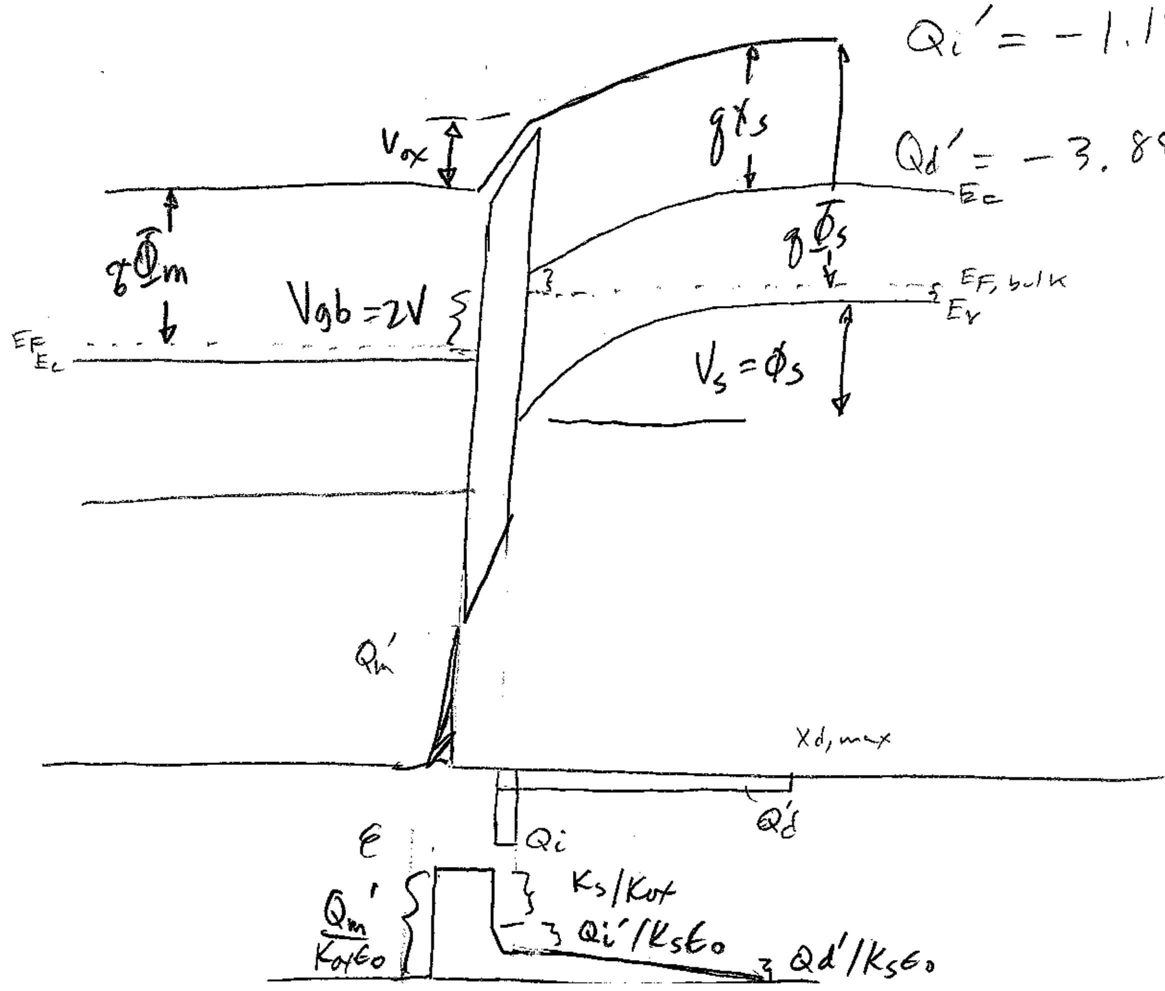
Inversion Charge:

$$V_{gb} = \phi_{ms} + 2|\phi_F| - \frac{Q_d' + Q_i'}{C_{ox}'}$$

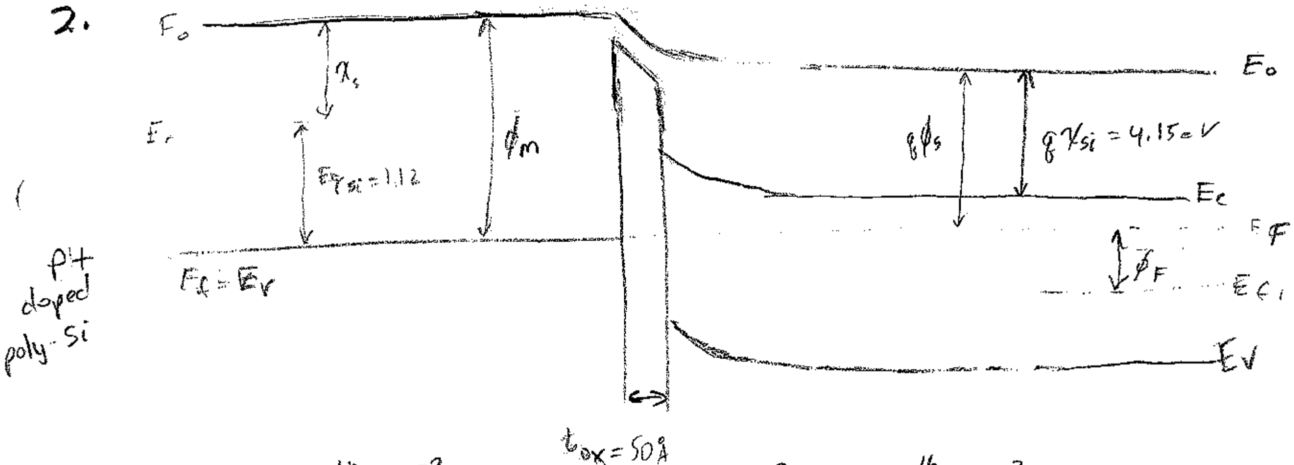
$$V_{gb} = \underbrace{\phi_{ms} + 2|\phi_F| - \frac{Q_d'}{C_{ox}'}}_{V_T} - \frac{Q_i'}{C_{ox}}$$

$$Q_i' = -1.1246\times10^{-6}\ \frac{C}{cm^2}$$

$$Q_d' = -3.88\times10^{-7}\ \frac{C}{cm^2}$$



2.



$\frac{Q_{ss}'}{q} = 5\times10^{10}\ cm^{-2}$ $\qquad$ $\frac{\rho_{ox}}{q} = 2\times10^{16}\ cm^{-3}$

$$C_{ox}' = \frac{k_{ox}\,\epsilon_{ox}}{t_{ox}} = \frac{3.9\times 8.854\times10^{-14}\frac{F}{cm}}{50\times10^{-8}\ cm} = 6.9\times10^{-7}\ \frac{F}{cm^2}$$

$$\Phi_s = \chi_{si} + (E_c - E_F)$$

$N_d = 10^{17}\ cm^{-3} \Rightarrow (E_c - E_F) = .15\ V$

$$\Phi_s = 4.05 + .15 = 4.2\ V$$

$$\Phi_m = \chi_s + E_g = 4.05 + 1.12$$

$$\Phi_{ms} = \Phi_m - \Phi_s = 1.12 - .15 = 0.97\,V$$

There exists Q_{ss} or ρ_{ox}, so $V_{FB} \neq \Phi_{ms}$

$$V_{FB} = \phi_{ms} - \frac{Q_{ss}'}{C_{ox}'} - \frac{1}{C_{ox}'}\int_0^{t_{ox}} \frac{x}{t_{ox}}\,\rho(x)\,dx$$

$$V_{FB} = \phi_{ms} - \left(\begin{matrix}\Delta V_{FB}\text{ due to}\\ \text{interface}\\ \text{charge}\end{matrix}\right) - \left(\begin{matrix}\Delta V_{FB}\text{ due to}\\ \text{oxide}\\ \text{charge}\end{matrix}\right)$$

$$= \phi_{ms} - \frac{q}{C_{ox}'}\left[Q_{ss}' + \rho_{ox}\frac{t_{ox}^2}{2\cdot t_{ox}}\right]$$

$$= 0.97V - \frac{1.6\times10^{-19}}{6.9\times10^{-7}}\Bigg[\underbrace{5\times10^{10} + 2\times10^{16}\frac{(50\times10^{-8})^2}{2(50\times10^{-8})}}_{5.5\times10^{10}}\Bigg]$$

$$V_{FB} = 0.97 - .0128$$

$$\underline{\underline{V_{FB} = 0.957\ V}}$$

2.

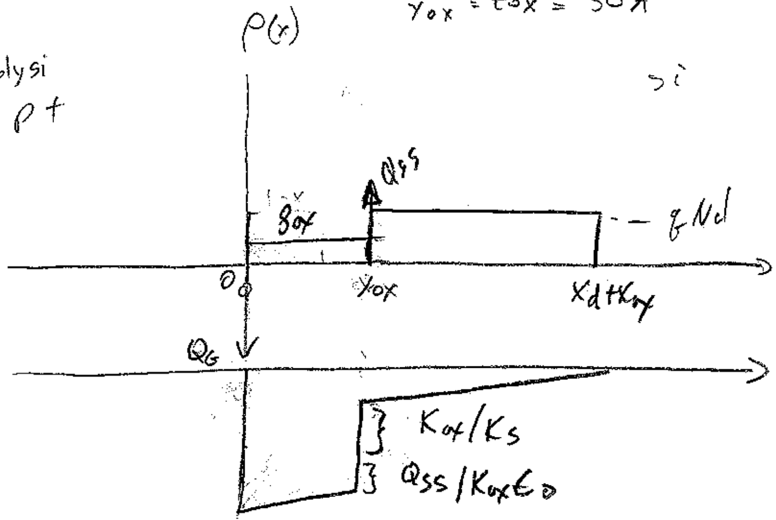
$y_{ox} = t_{ox} = 50\,\text{Å}$

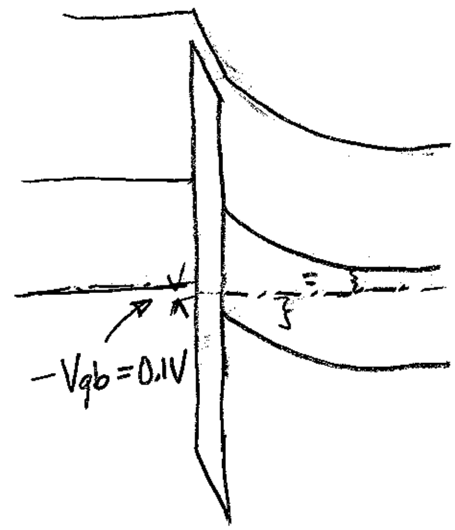
polysi p^+

si

EOSI

Edge-of-strong inversion





$Q_B' = qN_d X_{dmax}$

$X_{dmax} = \sqrt{\dfrac{2K_s\epsilon_0}{qN_d}|2\phi_F|}$; $\phi_F = \frac{kT}{q}\ln\left(\frac{N_d}{n_i}\right)$

$= 0.407\ V$

$Q_B' = \sqrt{2K_s\epsilon_0 q N_d |2\phi_F|}$

$V_T = V_{FB} - 2\phi_F - \frac{Q_B'}{C_{ox}'} = .957 - .814 - .238 = -0.1V$

FB

Flat-Band

$0.013V = \Phi_{ms} - V_{FB}$