ΔV_T Due to General Oxide Charge

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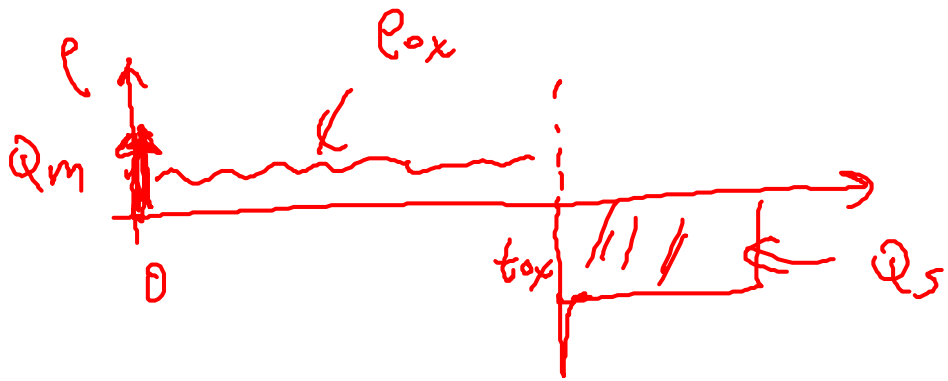
Consider an MOS structure with a general oxide charge density $\rho_{ox}(x)$. What is the ΔV_T due to ρ_{ox}?

Assume n-channel (p-type)

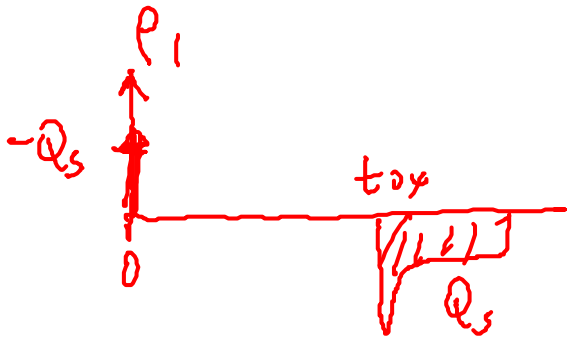


$$Q_{ox} \equiv \int_0^{t_{ox}} \rho_{ox}\, dx$$

By charge neutrality

$Q_m + Q_{ox} + Q_s = 0$

Break up into 2 parts



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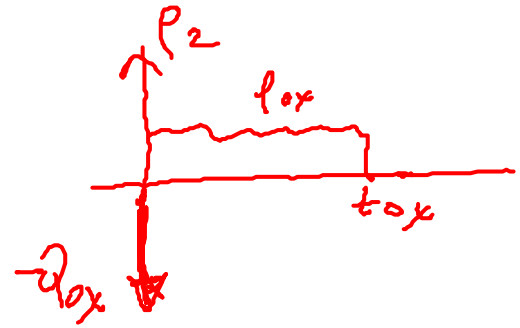
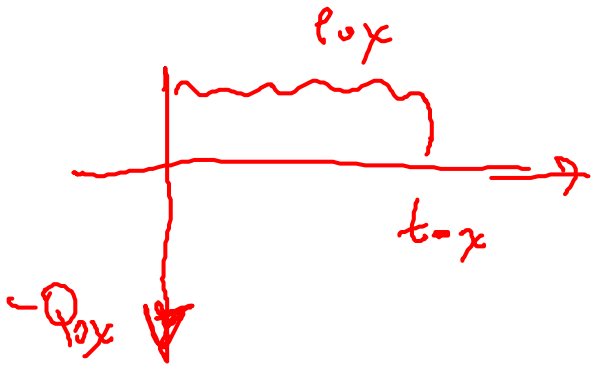


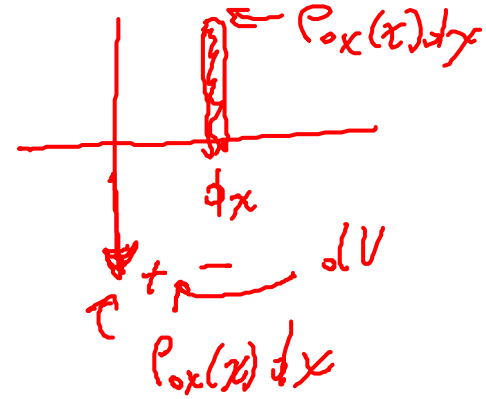
$\rho_1 \Rightarrow V_{ox1} = -\frac{Q_s}{\epsilon_{ox}} t_{ox} = -Q_s/C_{ox}$ as before

ρ_2? Make further use of superposition

$\rho_2 \Rightarrow \Delta V_T$



$\Longrightarrow$ consider individual dx segments



Each of these segments will yield

$$dV = -\left(\frac{\rho_{ox}\,dx}{\epsilon_{ox}}\right)x$$

Hence the total voltage drop due to the oxide charge is

$$\Delta V_{ox} = -\int_0^{t_{ox}} \frac{x\,\rho_{ox}}{\epsilon_{ox}}\,dx = -\frac{1}{\epsilon_{ox}}\int_0^{t_{ox}} x\,\rho_{ox}\,dx$$

$$= -\frac{1}{C_{ox}}\,\frac{1}{t_{ox}}\int_0^{t_{ox}} x\,\rho_{ox}\,dx$$

Thus

$$\Delta V_T = -\frac{1}{C_{ox}}\left(\frac{1}{t_{ox}}\right)\int_0^{t_{ox}} x\,\rho_{ox}(x)\,dx$$

If $\rho_{ox}(x) = +qN_f\,\delta(0)$

$\Rightarrow \Delta V_T = 0$ All the oxide charge is imaged by the gate

If $\rho_{ox}(x) = +qN_f\,\delta(t_{ox}/2)$

$\rightarrow \Delta V_T = -\frac{1}{2}qN_f/C_{ox}$

half oxide charge imaged by gate & half by Si

If $\rho_{ox}(x) = +qN_f\,\delta(t_{ox})$

$\Delta V_T = -qN_f/C_{ox}$

maximum effect on V_T

If $\rho_{ox} = \rho_0$ constant

$\Delta V_T = -\frac{1}{2}\rho_0 t_{ox}/C_{ox}$ Again $\frac{1}{2}$ charge imaged by Gate & $\frac{1}{2}$ by Si

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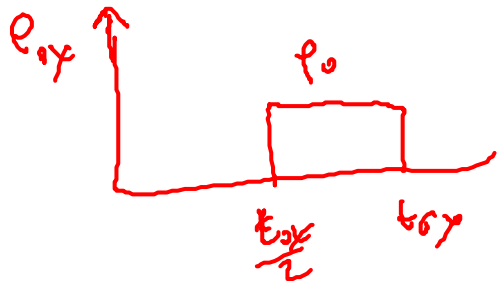


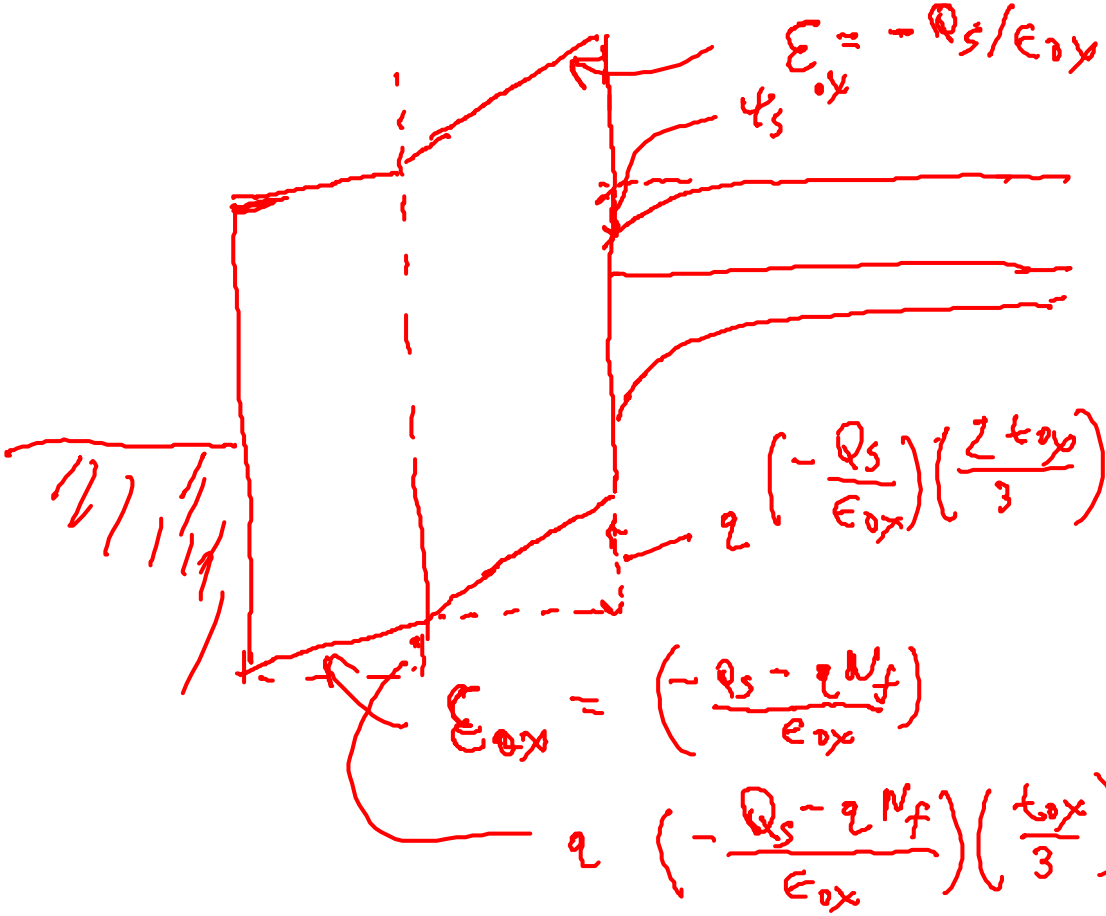
$$\Delta V_T = -\frac{1}{\epsilon_{ox}}\int_0^{t_{ox}} x\rho_{ox}\,dx$$

$$= -\frac{1}{\epsilon_{ox}}\frac{1}{2}\rho_0 x^2\Big|_{t_{ox}/2}^{t_{ox}}$$

$$= -\frac{1}{\epsilon_{ox}}\frac{1}{2}t_{ox}^2\left(1-\frac{1}{4}\right)\rho_0$$

$$= -\frac{1}{C_{ox}}\frac{3}{8}\rho_0 t_{ox}$$

Example $\rho_{ox}(x) = q N_f \, \delta(t_{ox}/3)$ at $\psi_s = 2\psi_F$



$$\Delta V_T = -\frac{1}{3}\frac{qN_f}{C_{ox}}$$

$$\Rightarrow V_{ox} = \underbrace{-\frac{Q_s}{\epsilon_{ox}}\left(\frac{2t_{ox}}{3}\right) + -\frac{Q_s}{\epsilon_{ox}}\left(\frac{t_{ox}}{3}\right)}_{\text{usual } V_{ox} \text{ at } V_T} - \frac{qN_f t_{ox}}{3\epsilon_{ox}}$$