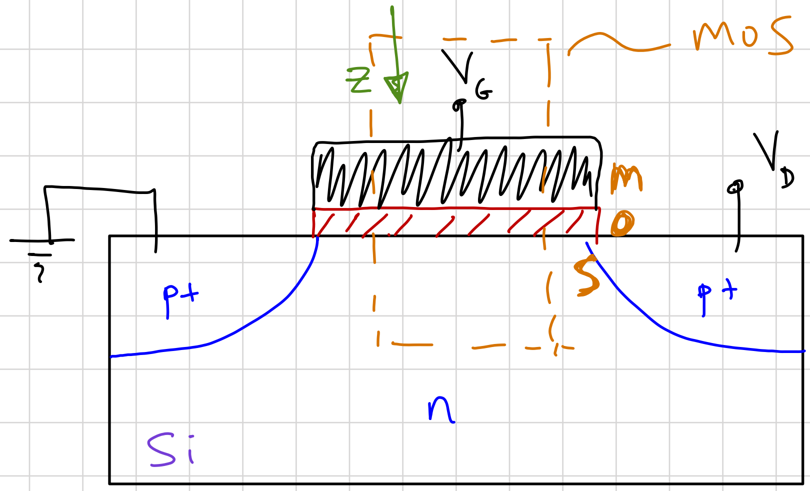
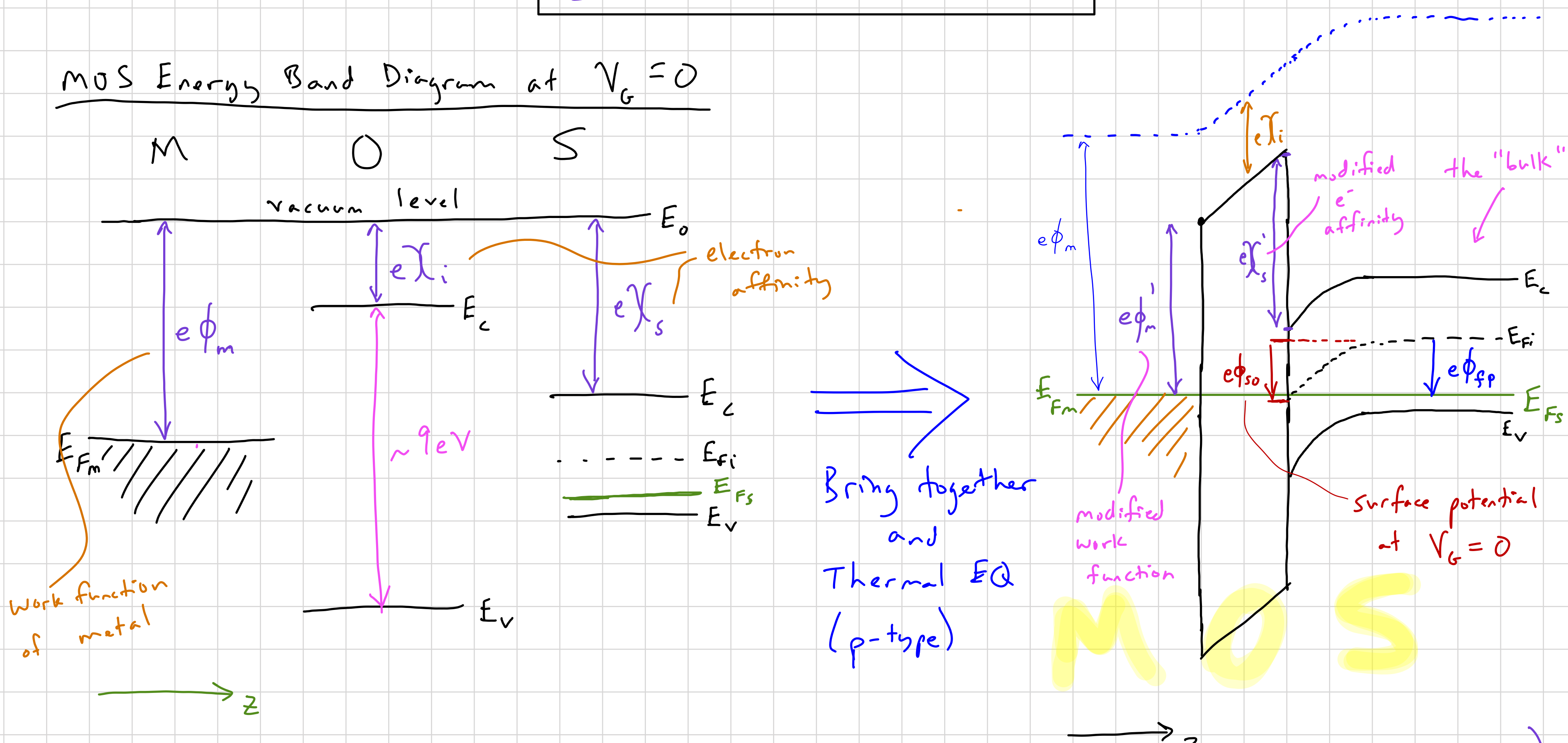
# Lecture #12 — MOS Capacitors

→ metal-oxide-semiconductor (MOS) Capacitor is the core of MOS Field-Effect Transistors (MOSFETs)




## MOS Energy Band Diagram at $V_G = 0$




→ For all MOS analysis, assume thermal EQ in S.C. (no current flowing in it)
≡ $E_{Fs}$ constant in S.C. and S.C. is grounded ⇒ $E_{Fs}$ does not move!!

→ Also fixed is distance between $E_v, E_c$, and $E_{Fm}$ → in S.C.

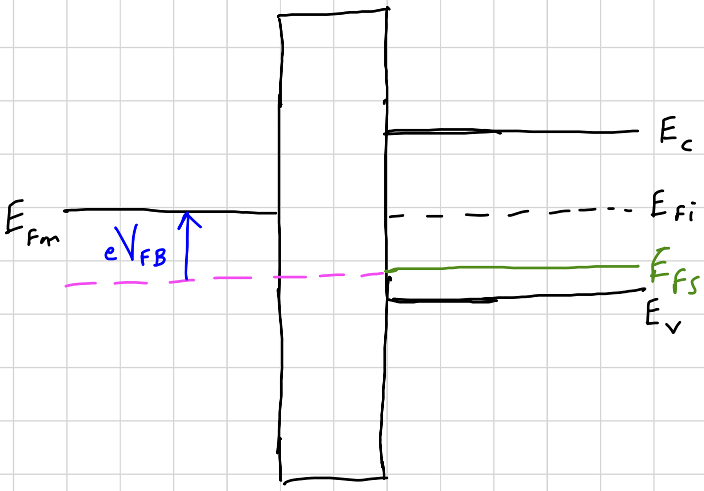
→ $E_{Fm}$ is like a handle that "moves" under applied $V_G$, dragging $E_{c,v}$ with it!!

→ All band bending created in the diagram above (@ $V_G = 0$) is from difference in metal & S.C. work functions:

$$\phi_{ms} = \left[\phi_m' - \left(\chi' + \frac{E_G}{2e} + \phi_{fp}\right)\right] \quad \text{— p-type S.C.}$$

$$\phi_{ms} = \phi_m' - \left(\chi' + \frac{E_G}{2e} - \phi_{fn}\right) \quad \text{— n-type S.C.}$$

Flat-Band Voltage: voltage required to achieve no band bending in S.C. (no space charge)




$V_{FB} = \phi_{ms}$ (when no charge in oxide)

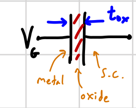
Typically, there is some amount of charge trapped in the oxide ($Q'_{ss}$) and is physically right next to S.C. surface:

$$\boxed{V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{ox}}}$$

$Q'_{ss}$: careful of units ($C/cm^2$ or $cm^{-2}$)

$C_{ox}$: mos capacitance

$C_{ox} = \frac{\varepsilon_{ox}\varepsilon_o}{t_{ox}}$

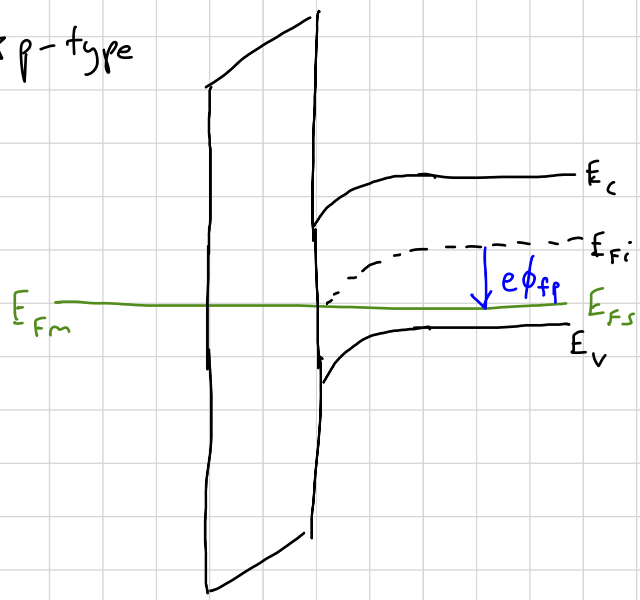



$Q = CV_G$

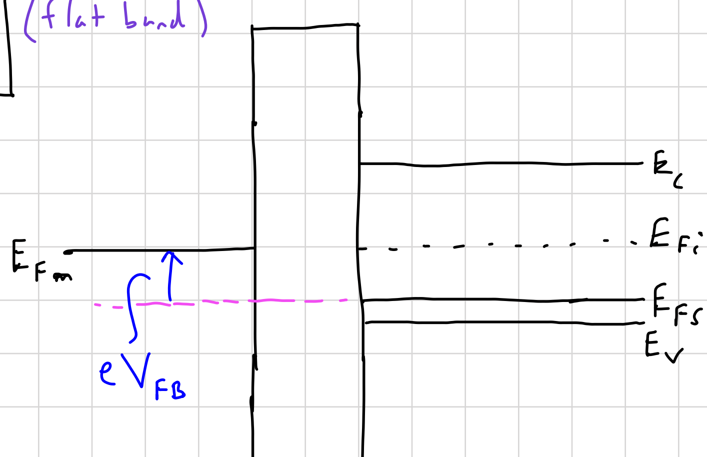
## Function of MOS Capacitor

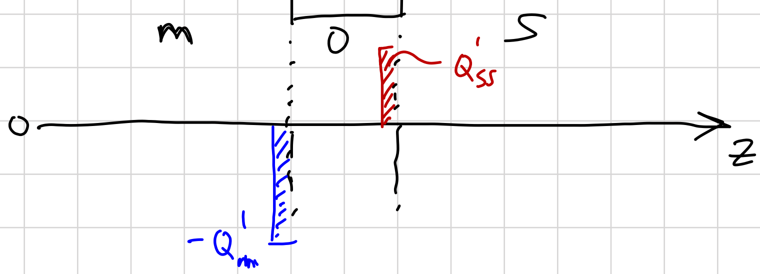
☆ p-type

$\boxed{V_G = 0}$

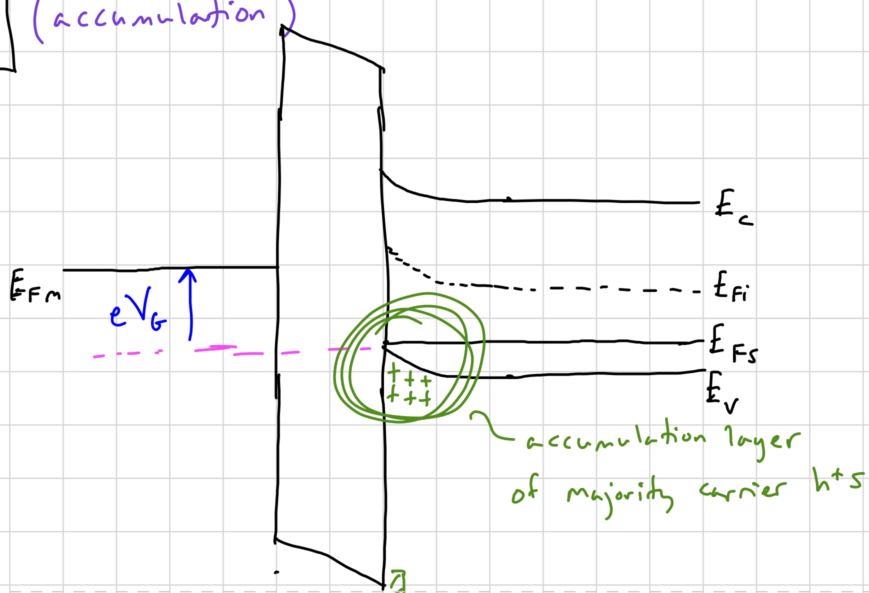



$\boxed{V_G = V_{FB}}$ (flat band)



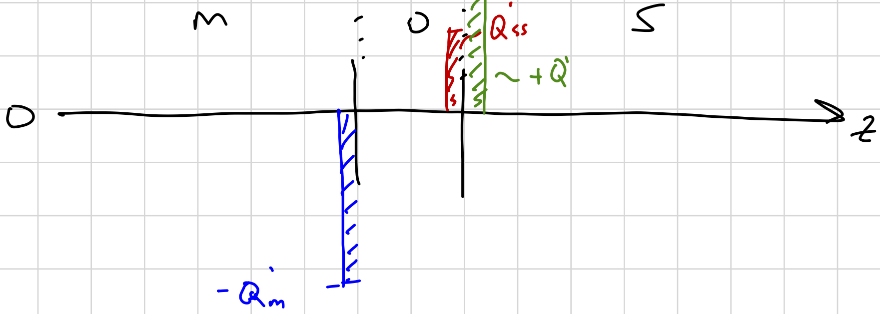

$\boxed{V_G < 0}$ (accumulation)




| p-type | n-type |
|---|---|
| $\phi_{fp} = V_t \ln\left(\frac{N_a}{n_i}\right)$ | $\phi_{fn} = V_t \ln\left(\frac{N_d}{n_i}\right)$ |

true for all bias conditions

$V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{ox}}$ → " "

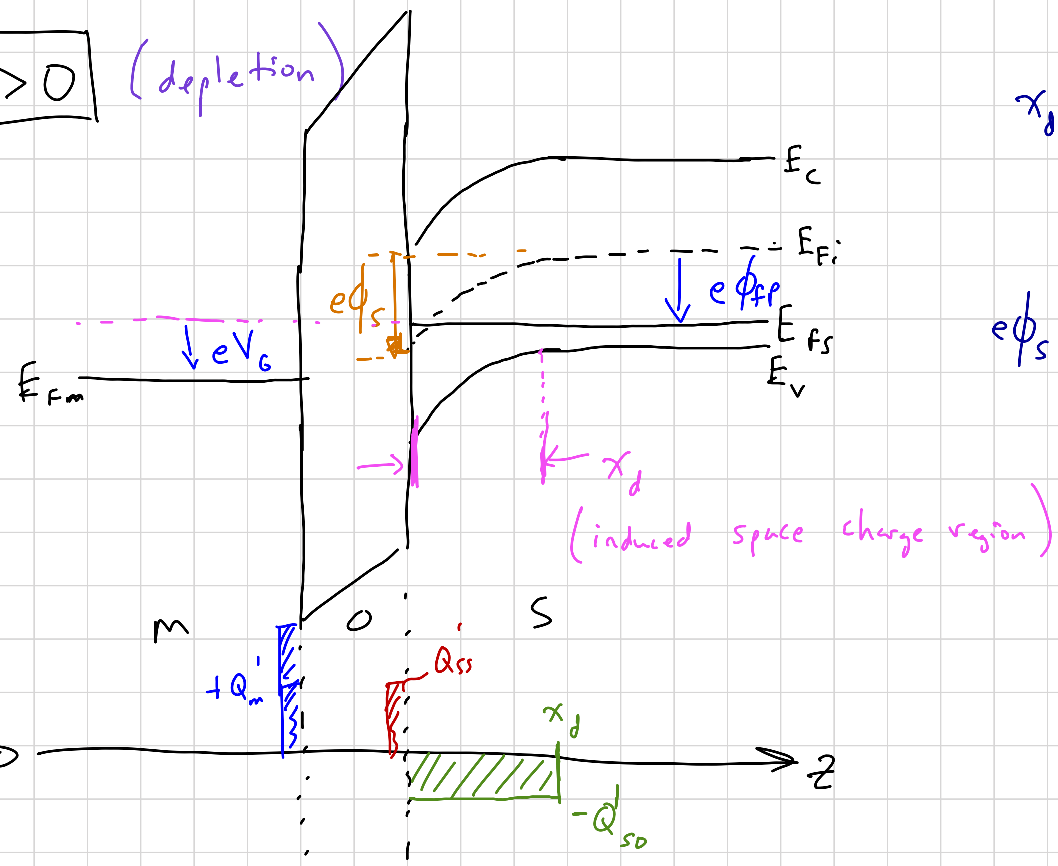



true for all bias conditions

$$x_d = \left(\frac{2\epsilon_s\epsilon_0\,\phi_s}{eN_a}\right)^{1/2} \qquad x_d = \left(\frac{2\epsilon_s\epsilon_0\,\phi_s}{eN_d}\right)^{1/2}$$

$$e\phi_s = E_{Fi}\Big|_{bulk} - E_{Fi}\Big|_{surface} \longrightarrow \quad " \quad "$$

$\boxed{V_G > 0}$ (depletion)



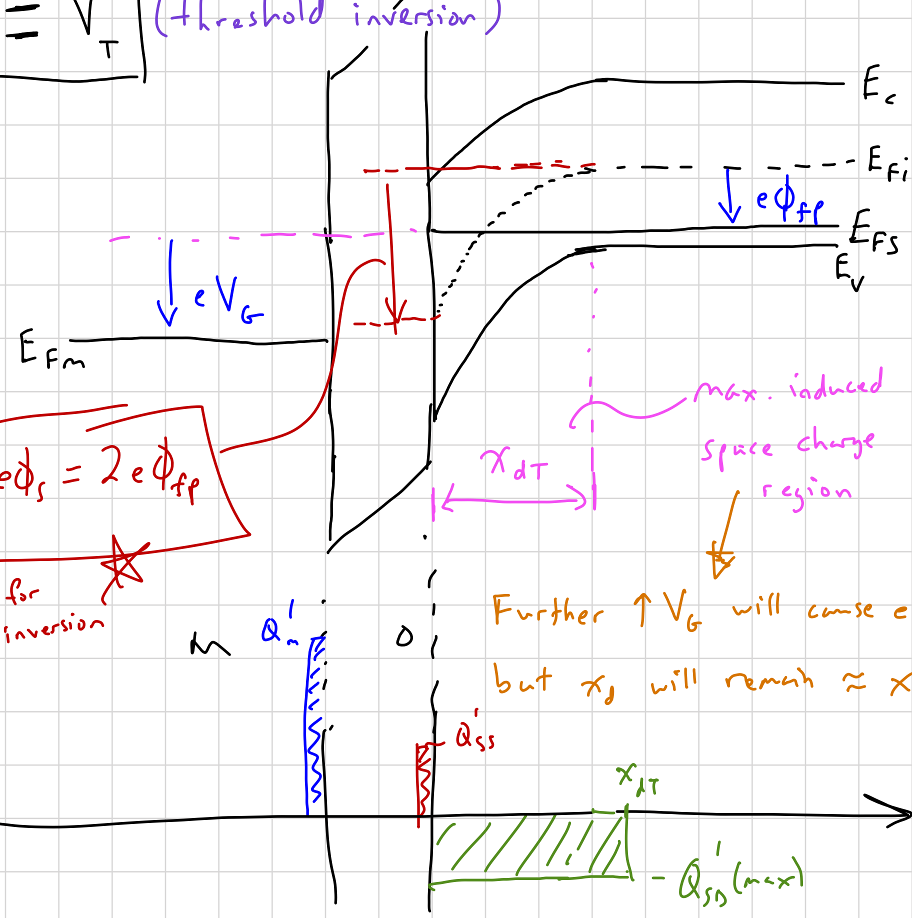

$\boxed{V_G = V_T}$ (threshold inversion)

$$x_{dT} = \left(\frac{4\epsilon_s\epsilon_0\,\phi_{fp}}{eN_a}\right)^{1/2} \qquad x_{dT} =$$

$$\left|Q_{SD}'(max)\right| = eN_a x_{dT} \qquad \left|Q_{SD}'(max)\right| = eN_d x_{dT}$$

$$V_{TN} = \frac{\left|Q_{SD}'(max)\right|}{C_{ox}} - \frac{Q_{ss}'}{C_{ox}} + \phi_{ms} + 2\phi_{fp}$$

$$V_{TP} = \left(-\left|Q_{SD}'(max)\right| - Q_{ss}'\right)\frac{t_{ox}}{\epsilon_{ox}\epsilon_0} + \phi_{ms} - 2\phi_{fn}$$

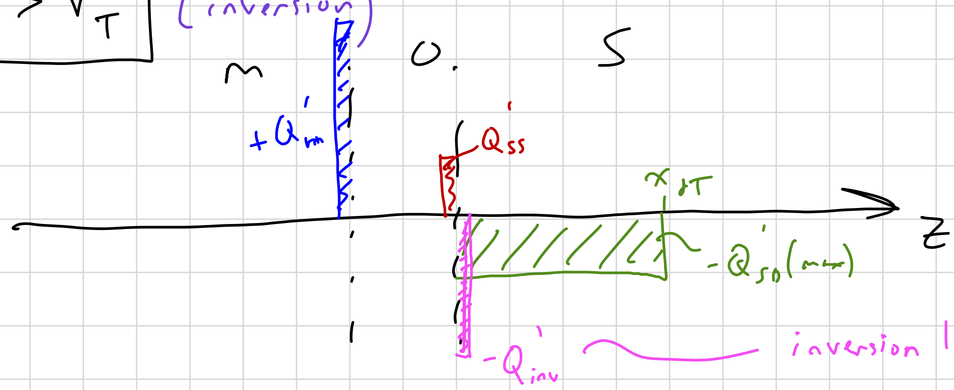



$e\phi_s = 2e\phi_{fp}$

condition for threshold inversion

Further $\uparrow V_G$ will cause $e\phi_s \uparrow$ but $x_d$ will remain $\approx x_{dT}$

$\boxed{V_G > V_T}$ (inversion)




inversion layer (must form to balance added $Q_m'$ charge)