VE320 RC - Charpter 10

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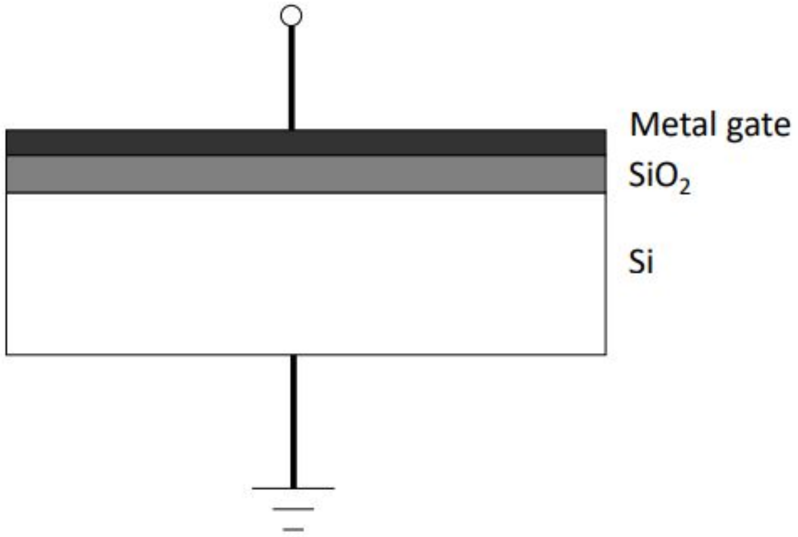
8.2

Outline

- MOS Structure
- MOS Capacitance
- MOSFET

MOS Structure



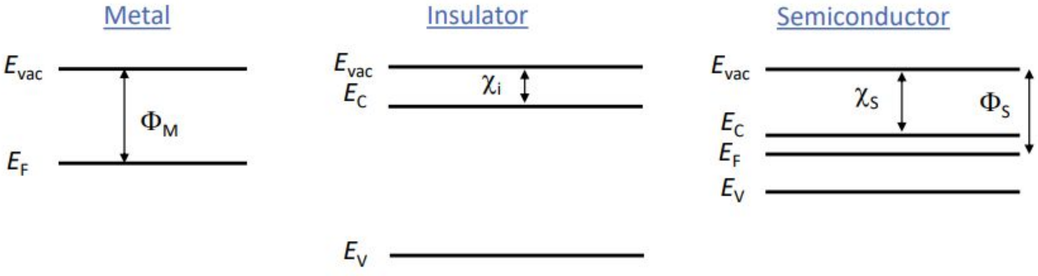
MOS Structure

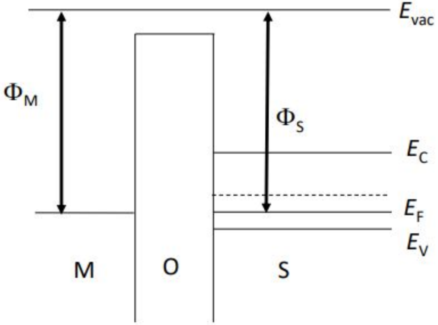
Rules:

1. Constancy of Fermi level in equilibrium

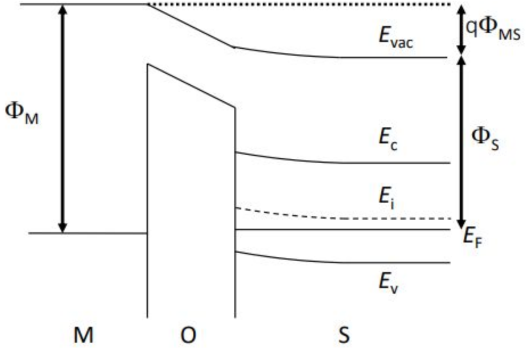
2. Continuity of vacuum level across interfaces.

3. Equilibrium configuration depends on metal and semiconductor work function





Consider special case:
Ideal MOS structure
$\Phi_M = \Phi_S$



Non-ideal MOS structure
$\Phi_M \neq \Phi_S$

MOS Structure

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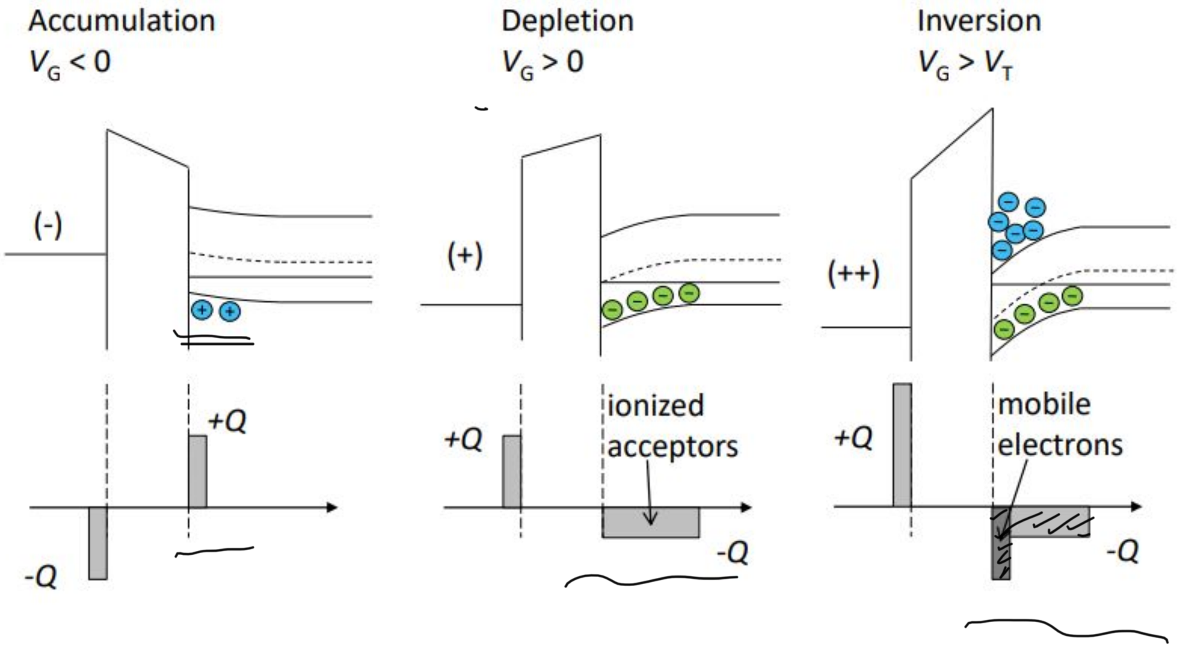
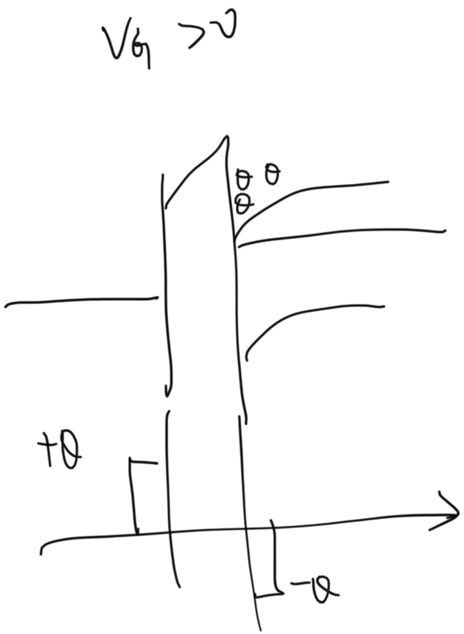
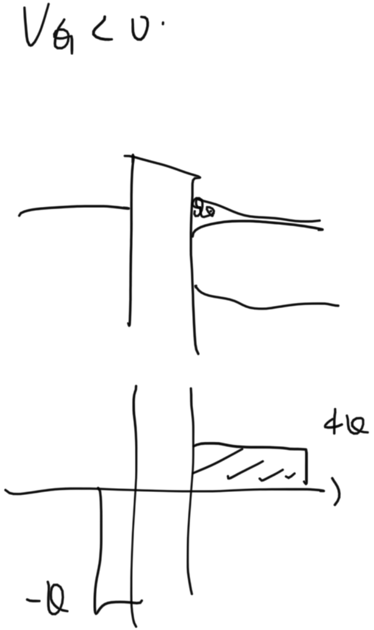
p-type NMOS

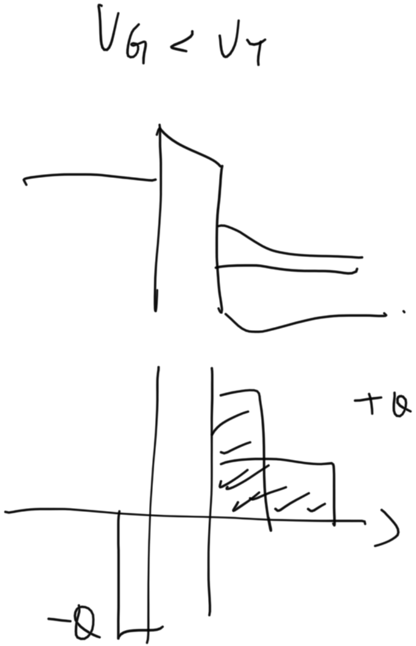


MOS Structure

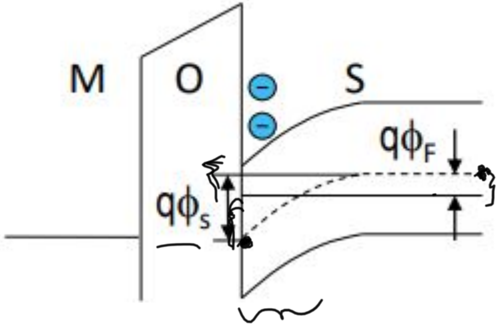
n-type PMOS?







MOS Structure



Surface Potential: $$\phi_s = \frac{1}{q}\left[E_{i,bulk} - E_{i,surface}\right]$$

ϕ_F Potential Difference:

ϕ_{FN} ϕ_{FP}

n-type Semiconductor

$$\phi_F = -\frac{kT}{q} ln\left(\frac{N_D}{n_i}\right)$$

p-type Semiconductor

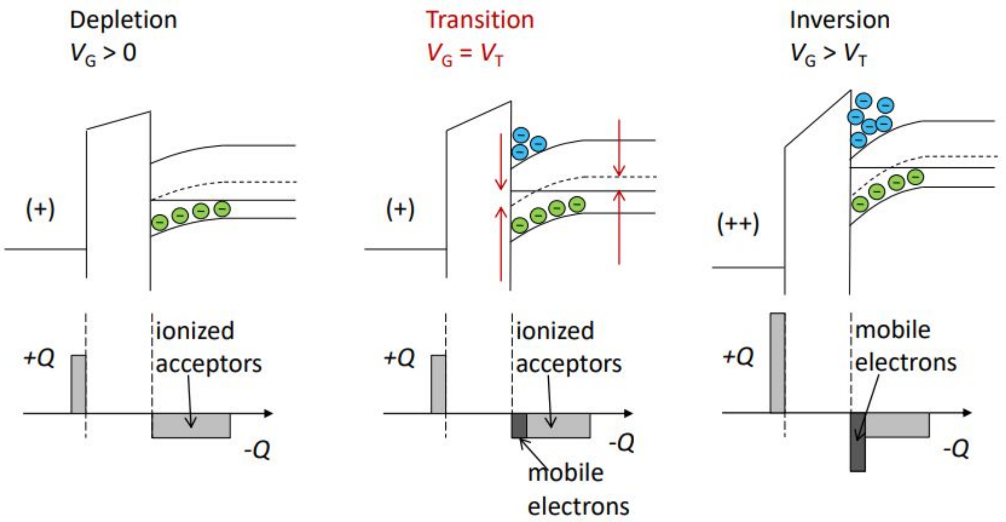
$$\phi_F = +\frac{kT}{q} ln\left(\frac{N_A}{n_i}\right)$$

Space charge width: $$x_d = \left(\frac{2\epsilon_s\phi_s}{eN_a}\right)^{1/2}$$

MOS Structure

Threshold inversion point: $\phi_S = 2\phi_F$

Concentration of electrons at surface = Concentration of holes in bulk



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

$$|Q'_{SD}(\max)| = eN_a\, x_{dT}$$

0

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

$$V_{TN} = (|Q'_{SD}(\max)| - Q'_{ss})\left(\frac{t_{ox}}{\epsilon_{os}}\right) + \phi_{ms} + 2\phi_{fp}$$

$$V_{TN} = \frac{|Q'_{SD}(\max)|}{C_{ox}} + V_{FB} + 2\phi_{fp}$$

MOS Structure

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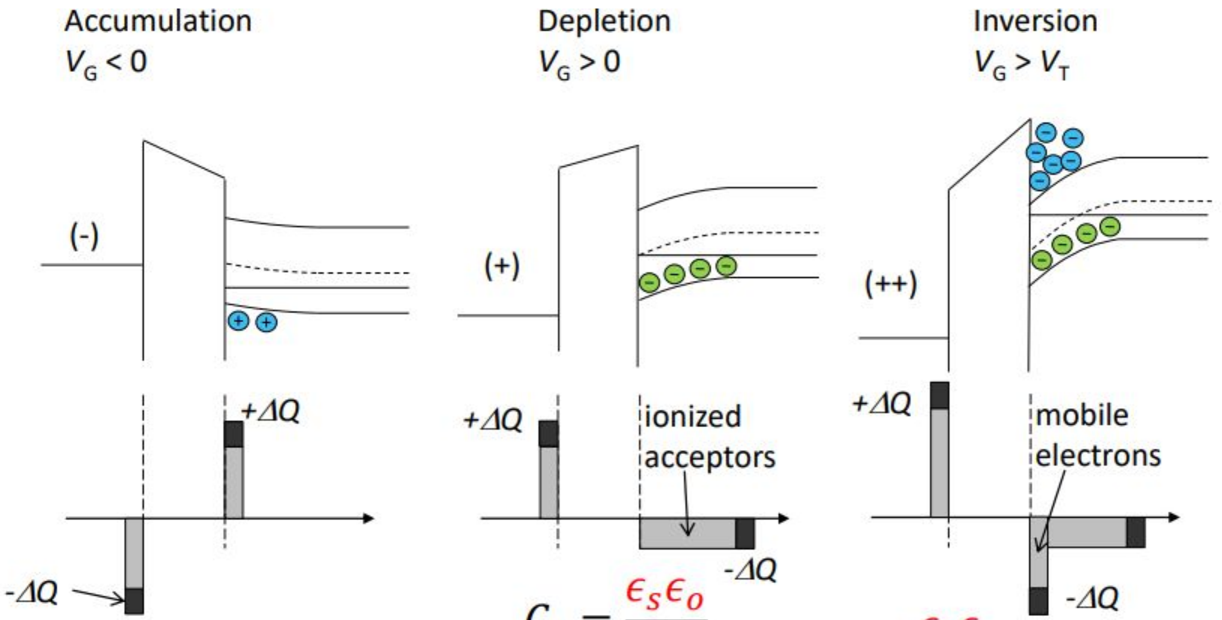
metal-semiconductor work function difference:

p-type $\phi_{ms} \equiv \left[\phi'_m - \left(\chi' + \frac{E_g}{2e} + \phi_{fp}\right)\right]$ n-type $\phi_{ms} = \phi'_m - \left(\chi' + \frac{E_g}{2e} - \phi_{fn}\right)$

V_{FB}=Voltage needed for flat energy bands (analogous to V_{bi})

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

MOS Capacitance - p-type NMOS

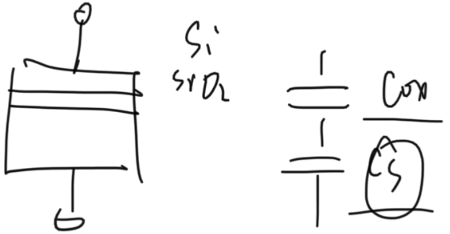


$$C_S \rightarrow \infty$$
$$C = C_{ox}$$

$$C_S = \frac{\epsilon_S \epsilon_o}{W}$$
$$C = \left(\frac{1}{C_{ox}} + \frac{1}{C_S}\right)^{-1}$$

$$C_S = \frac{\epsilon_S \epsilon_o}{W_T}$$
high ω

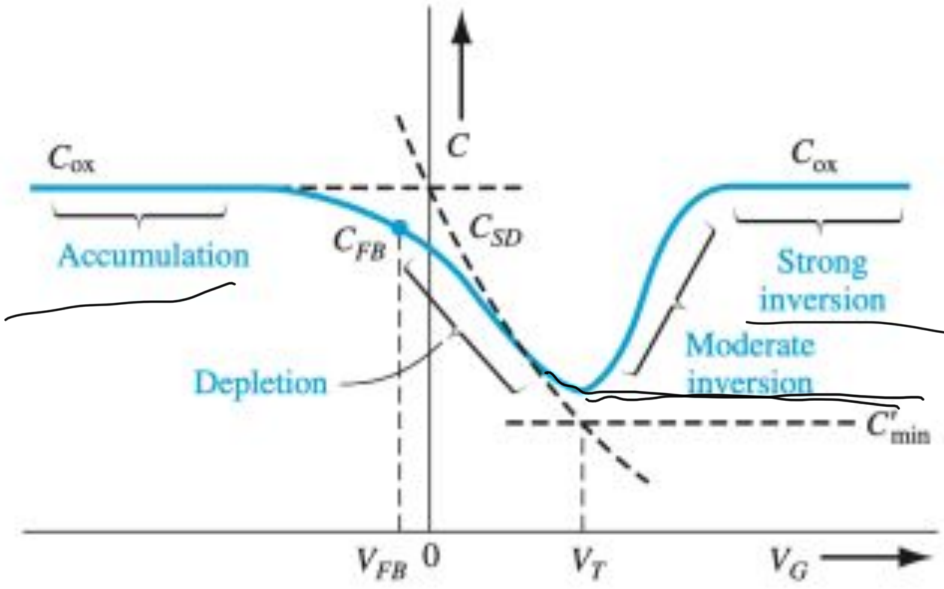
$$C_S \rightarrow \infty$$
low ω



$$\boxed{C = \left(\frac{1}{C_{ox}} + \frac{1}{C_S}\right)^{-1}}$$

∞

MOS Capacitance - p-type NMOS



low w

high w

$$C'(\text{acc}) = C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$$

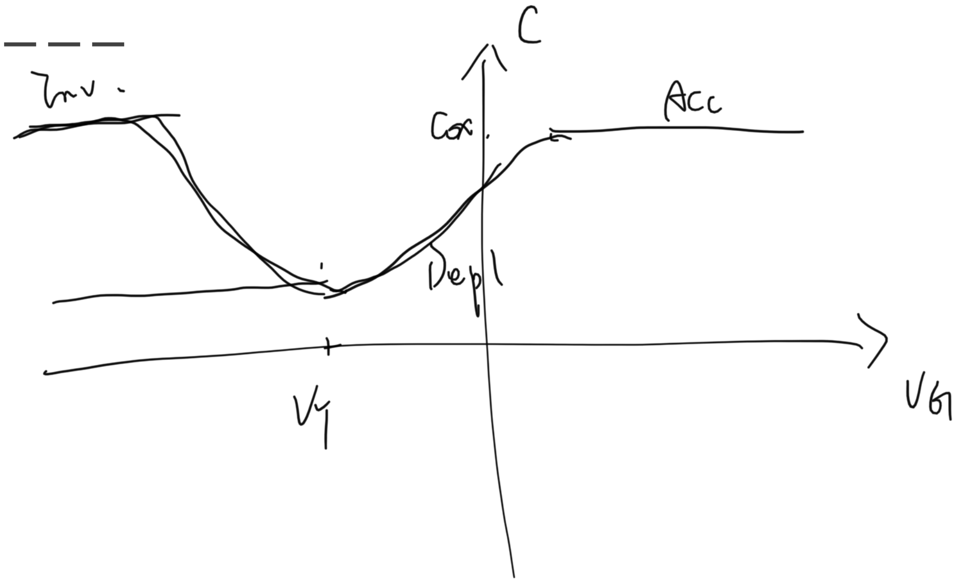
$$C'(\text{depl}) = \frac{\epsilon_{ox}}{t_{ox} + \left(\frac{\epsilon_{ox}}{\epsilon_s}\right) x_d}$$

$$C'(\text{inv}) = C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$$

$$C'(\text{min}) = \frac{\epsilon_{ox}}{t_{ox} + \left(\frac{\epsilon_{ox}}{\epsilon_s}\right) x_{dT}}$$

$$C'(\text{FB}) = \frac{\epsilon_{ox}}{t_{ox} + \left(\frac{\epsilon_{ox}}{\epsilon_s}\right)\sqrt{\left(\frac{kT}{e}\right)\left(\frac{\epsilon_s}{eN_a}\right)}}$$

MOS Capacitance - n-type PMOS

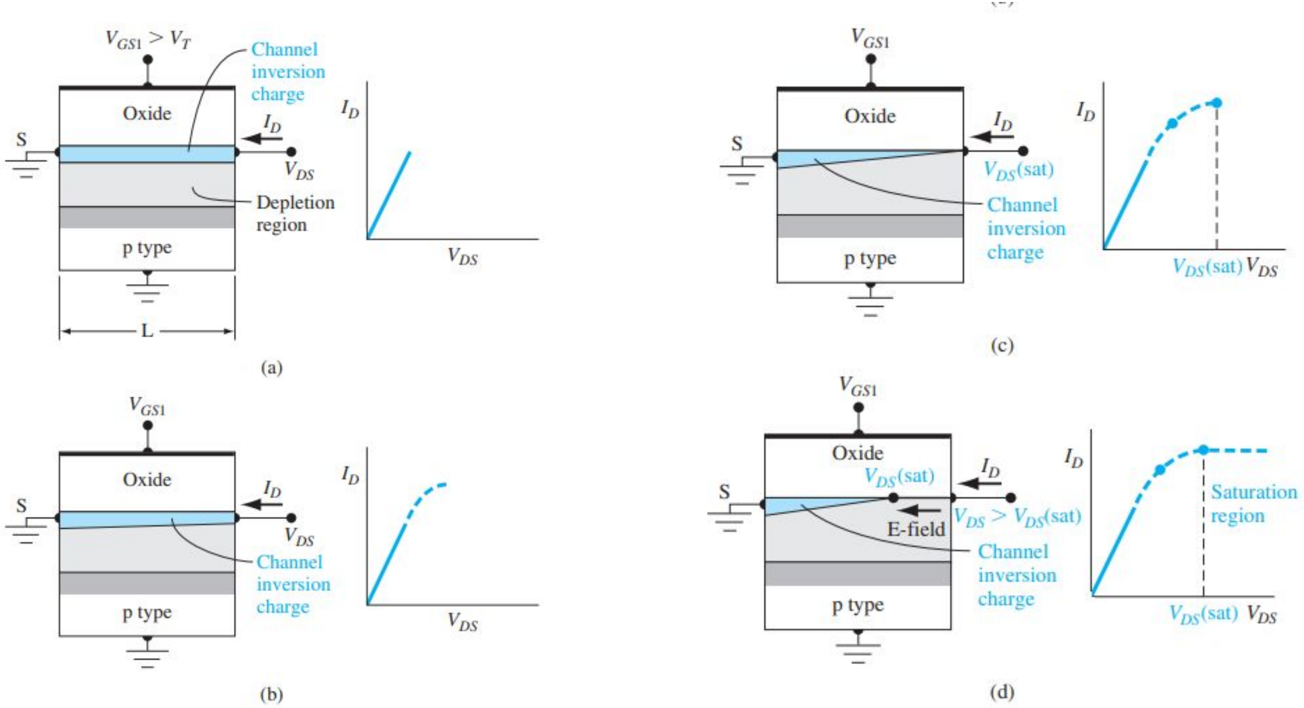


MOSFET

Enhancement mode: the semiconductor substrate is not inverted directly under the oxide with zero gate voltage

Depletion mode: a channel region exists under the oxide with zero gate voltage

MOSFET



When V_{DS} increases, the inversion charge density around the drain decreases.

When $V_{DS} = V_{DS(sat)}$, it reaches "pinch off"

MOSFET

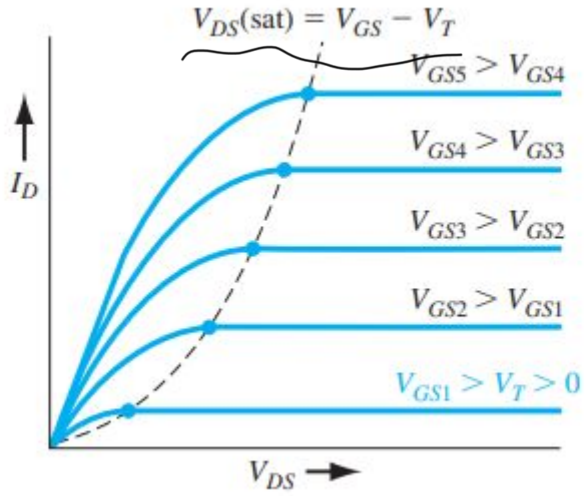
$V_{GS} < V_T$: $I_{DS} = 0$

$V_{GS} > V_T$ and $V_D < V_{GS} - V_T$:

$$I_D = \frac{W\mu_n C_{ox}}{2L}\left[2(V_{GS} - V_T)V_{DS} - V_{DS}^2\right]$$

$V_{GS} > V_T$ and VD $\geq V_{GS} - V_T$:

$$I_D = \frac{W\mu_n C_{ox}}{2L}(V_{GS} - V_T)^2$$

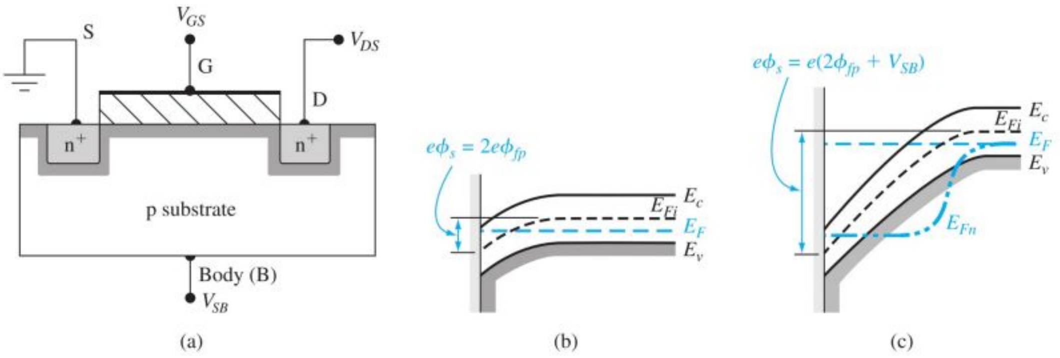


Transconductance

The change in drain current with respect to the corresponding change in gate voltage.

$$g_m = \frac{\partial I_D}{\partial V_{GS}}$$
$$= \begin{cases} \mu_n C_{ox} \dfrac{W}{L} V_{DS}, & 0 < V_{DS} < V_{GS} - V_T \\ \mu_n C_{ox} \dfrac{W}{L} (V_{GS} - V_T), & V_{DS} > V_{GS} - V_T \end{cases}$$

Substrate Bias Effects



$$V_{SB} = 0: \quad Q'_{SD}(\text{max}) = -\sqrt{2e\varepsilon_s N_a(2\phi_{fp})}$$

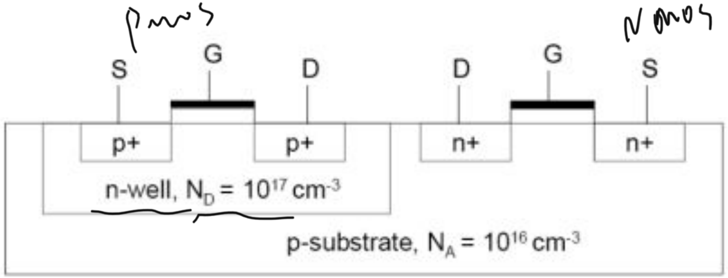
$$V_{SB} > 0: \quad Q'_{SD} = -\sqrt{2e\varepsilon_s N_a(2\phi_{fp} + V_{SB})}$$

$$\Delta V_T = -\frac{\Delta Q'_{SD}}{C_{ox}} = \frac{\sqrt{2e\varepsilon_s N_a}}{C_{ox}}\left[\sqrt{2\phi_{fp} + V_{SB}} - \sqrt{2\phi_{fp}}\right]$$

$$= \gamma\left[\sqrt{2\phi_{fp} + V_{SB}} - \sqrt{2\phi_{fp}}\right], \qquad \gamma = \frac{\sqrt{2e\varepsilon_s N_a}}{C_{ox}}$$

Practice

Consider the following Si CMOS Transistor. Calculate the threshold voltage for both NMOS and PMOS.



$x_{ox} = 40$ nm

$\phi_{ms} = -0.6$ V, NMOS

$\phi_{ms} = -0.4$ V, PMOS

Thanks