VE320 RC

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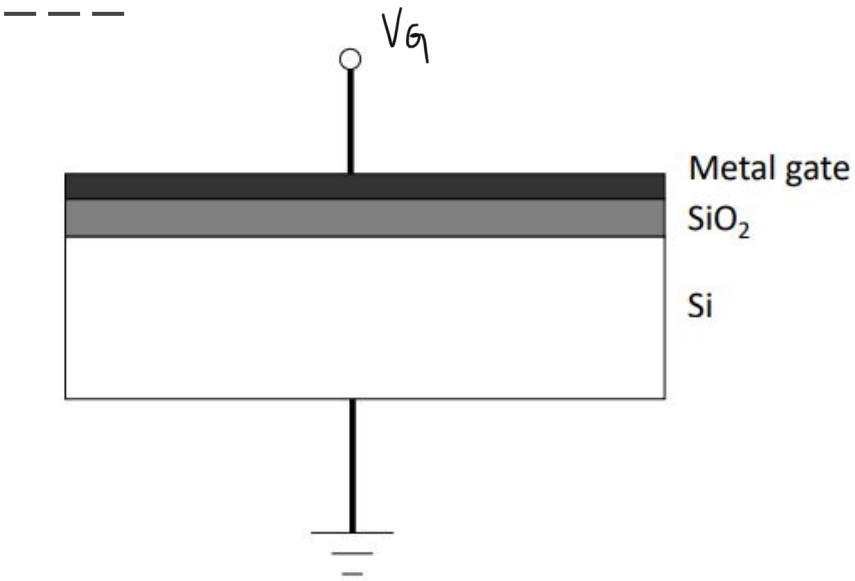
7.22

Outline

- MOS Structure
- MOS Capacitance
- MOSFET

MOS Structure



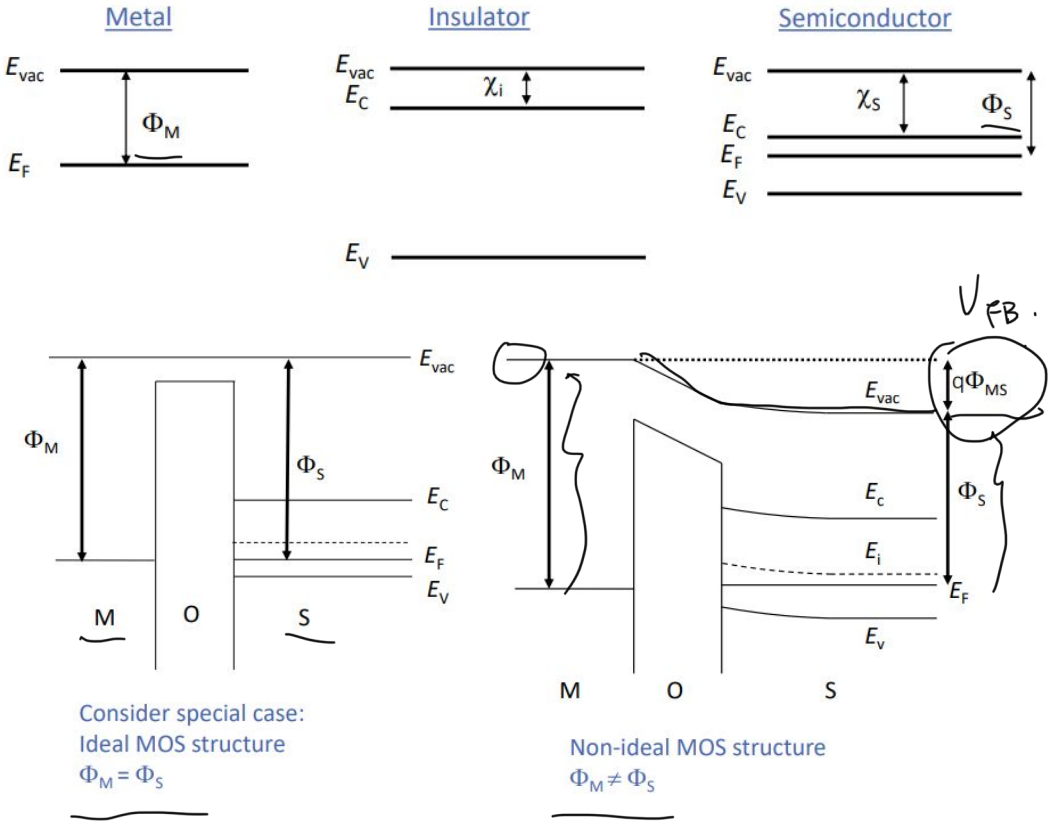
MOS Structure

Rules:

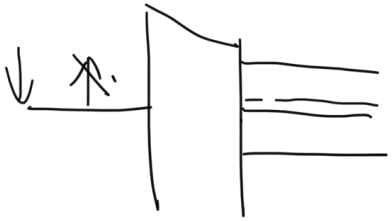
1. Constancy of Fermi level in equilibrium

2. Continuity of vacuum level across interfaces.

3. Equilibrium configuration depends on metal and semiconductor work function

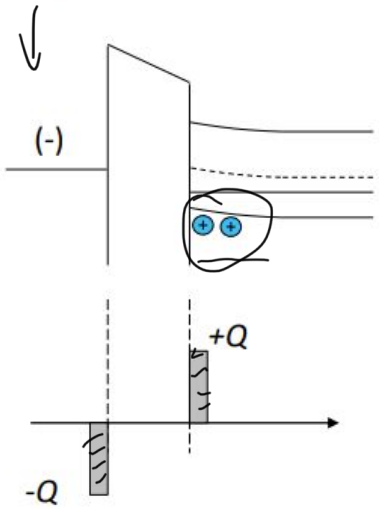


MOS Structure

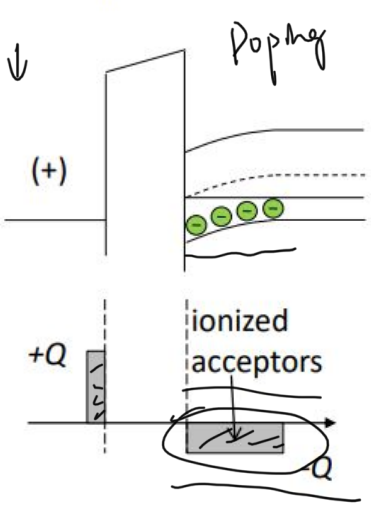


p-type NMOS

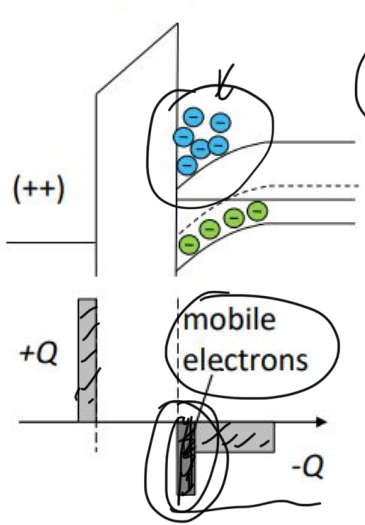
Accumulation
$V_G < 0$



Depletion
$V_G > 0$



Inversion
$V_G > V_T$

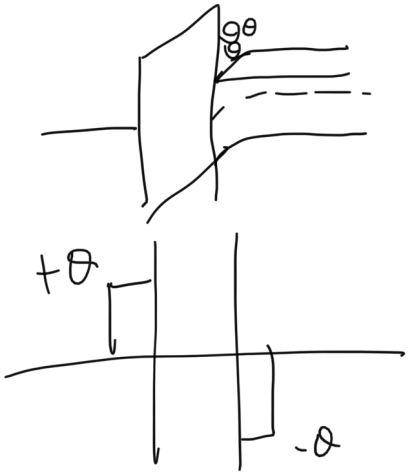


MOS Structure

n-type PMOS?

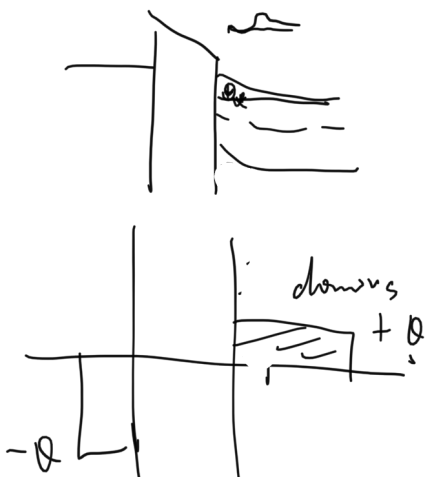
Accumulation

$V_{GT} > 0$



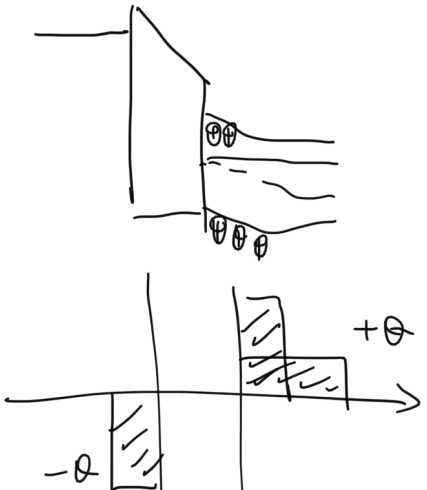
Depletion

$V_{GT} < 0$



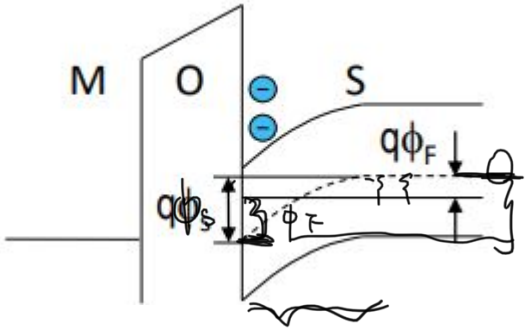
Inversion

$V_{GT} < V_T$



MOS Structure

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



ϕ_F Potential Difference:

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

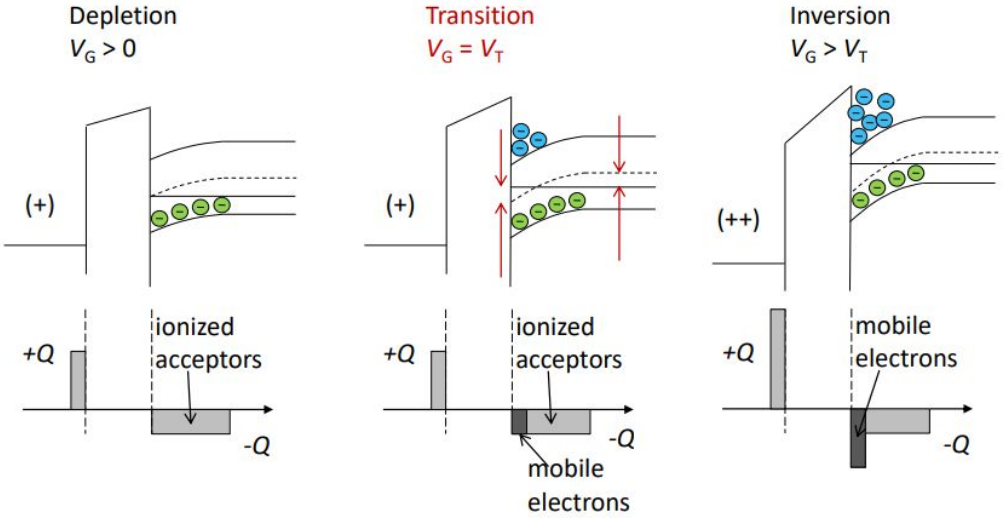
$\phi_s = \phi_F + \phi_F$

$\phi_s = 2\phi_F$

MOS Structure

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

Concentration of electrons at surface = Concentration of holes in bulk



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

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

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

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

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

MOS Structure

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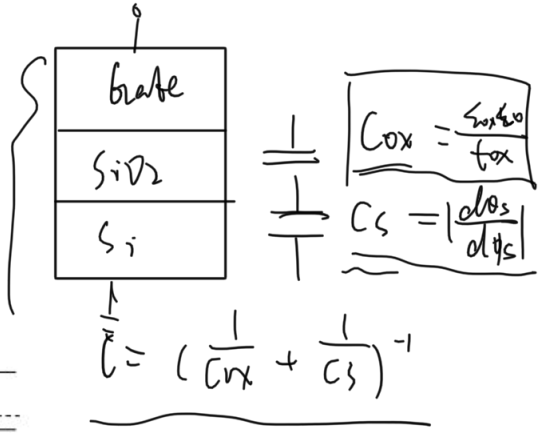
metal-semiconductor work function difference:

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

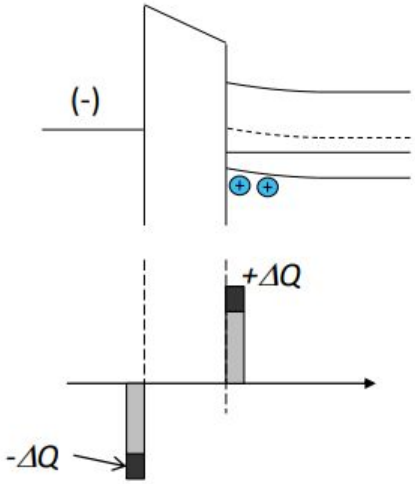
V_{FB}=Voltage needed for flat energy bands (analogous to V_{bi})

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

MOS Capacitance - p-type NMOS



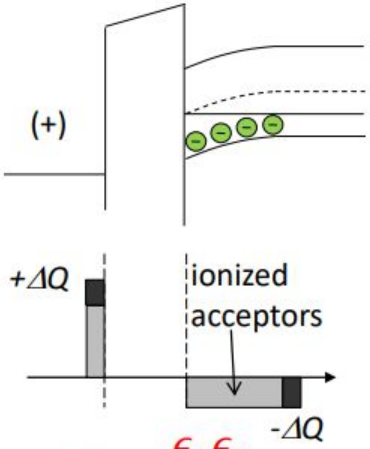
Accumulation
$V_G < 0$



$C_S \to \infty$

$C = C_{ox}$

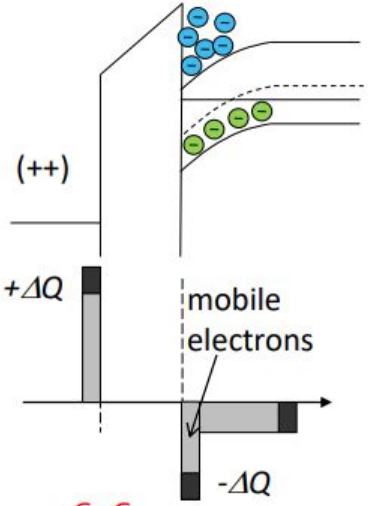
Depletion
$V_G > 0$



$$C_S = \frac{\epsilon_S \epsilon_O}{W}$$

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

Inversion
$V_G > V_T$



$$C_S = \frac{\epsilon_S \epsilon_O}{W_T}$$

high ω

$C_S \to \infty$

low ω

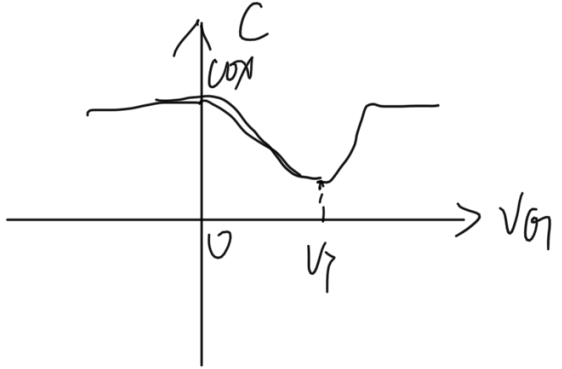
MOS Capacitance - p-type NMOS

$C = C_{ox}$

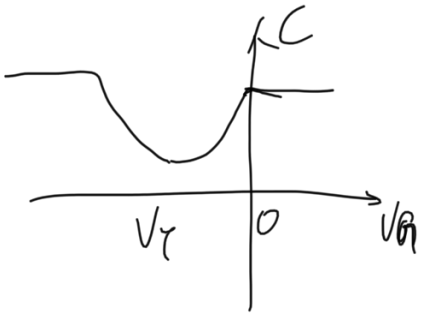
$C_s \downarrow$

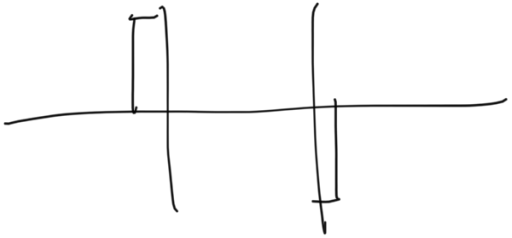
$C \downarrow$

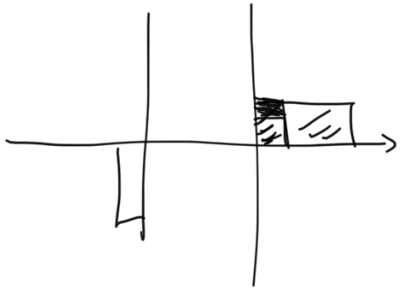
$C =$

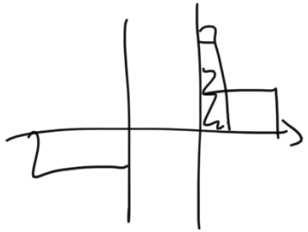


MOS Capacitance - n-type PMOS









$C = C_{ox}$

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

$\downarrow \quad V_G \downarrow$

$C = C_{ox}$

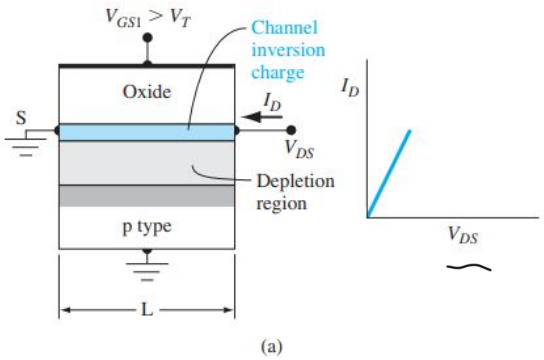
MOSFET

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

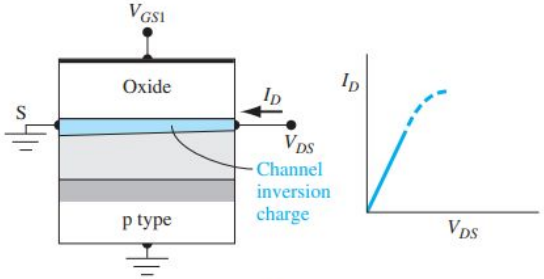
Depletion mode: a channel region exists under the oxide with zero gate voltage

pinch off

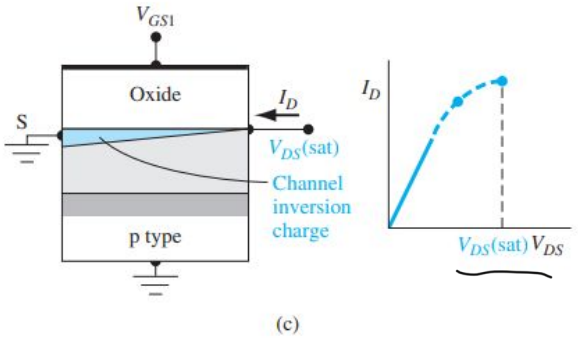
MOSFET



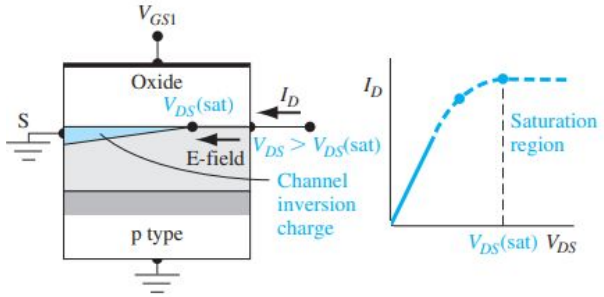
(a)



(b)



(c)



(d)

When V_{DS} increases, the inversion charge density around the drain decreases.
When $V_{DS} = V_{DS(sat)}$, it reaches "pinch off"

MOSFET

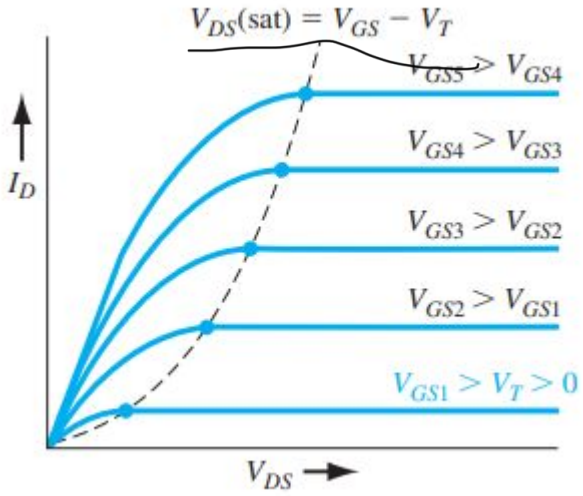
$V_{GS} < V_T$: $I_{DS} = 0$

$V_{GS} > V_T$ 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 $V_D \geq V_{GS} - V_T$:

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



Thanks