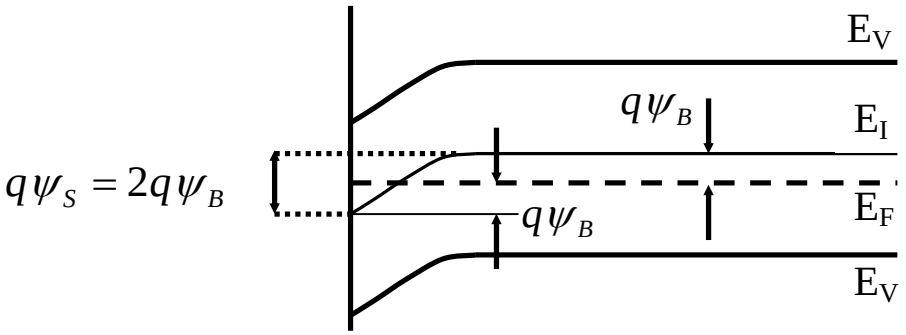
Threshold Voltage for an MOS Junction

At threshold, the concentration of electrons at the surface equal to the concentration of holes in the bulk: $n_{surface} = p_{p0}$



At threshold, $\psi_s = 2\psi_B$. It is assumed that all the charge in the semiconductor is due to the depletion region.

$$V_{TH} = V_{ox,T} + 2\psi_B = dE_{ox,T} + 2\psi_B$$

$$= d\frac{\varepsilon_S}{\varepsilon_{ox}}E_{s,T} + 2\psi_B \qquad \text{Boundary: } \varepsilon_s E_s = \varepsilon_{ox}E_{ox}$$

$$= \frac{|Q_D|}{C_{ox}} + 2\psi_B \qquad \text{By Gauss's Law } \varepsilon_s E_s = |Q_D|$$

With $C_{ox} = \frac{\varepsilon_{ox}}{d}$: Oxide Capacitance per unit Area

$$V_{TH} = \frac{|Q_D|}{C_{ox}} + 2\psi_B$$

For a real MOSFET, $V_{TH}' = V_{TH} - V_{FB}$

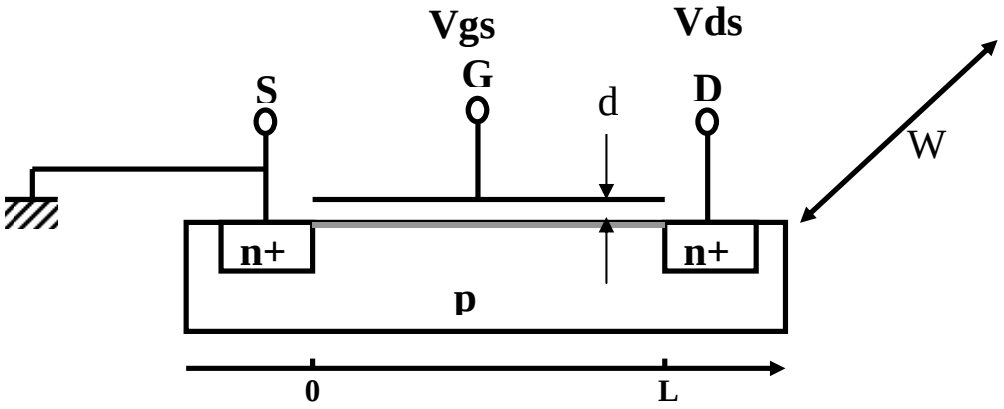
$$V_{TH} = \varphi_{ms} - \frac{Q_{ss}}{C_{ox}} \pm 2|\psi| \pm \frac{|Q_D|}{C_{ox}}$$ (+ for p-type, - for n-type)

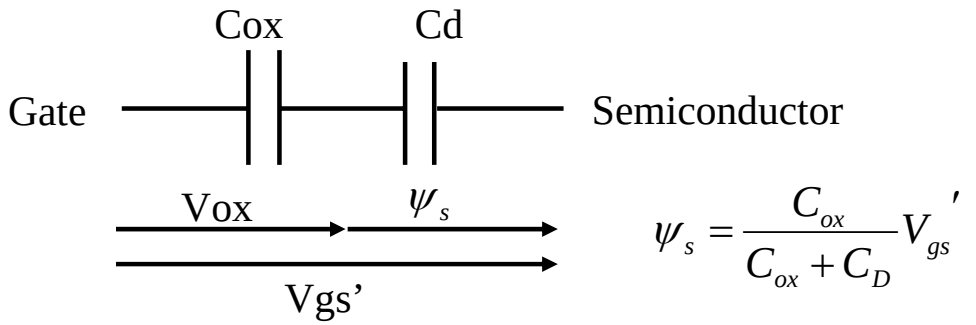
where Q_{ss} is the charge trapped at the oxide/semiconductor interface.

MOSFET
(Metal Oxide Semiconductor Field Effect Transistor)

Subthreshold

$$n(0) = n_{p0} Exp[q\psi_s / kT]$$





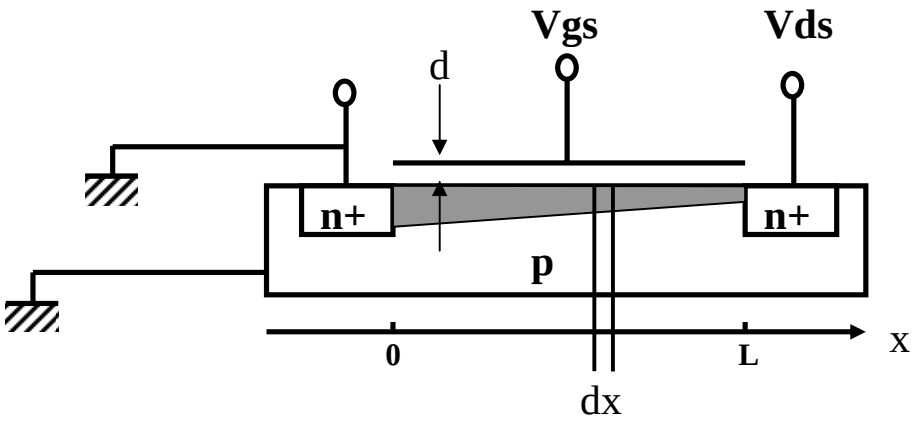
$$\psi_s = \frac{C_{ox}}{C_{ox} + C_D} V_{gs}'$$

$$n(L) = n_{p0} Exp[q(\psi_s - V_{ds}) / kT] \cong 0$$

$$\frac{J_{ds,drift}}{J_{ds,diffusion}} = \frac{nq\mu_n E}{qD_n \dfrac{n(0) - n(L)}{L}} \cong \frac{V_{ds}}{V_T}$$

$$J_{ds} \propto Exp\left[\frac{qV_{gs}}{kT}\right]$$

Ohmic Mode (Triode)



$Q_n(x) = C_{ox}(V_{gs} - V_{TH} - V(x))$ With $C_{ox} = \frac{\varepsilon_{ox}}{d}$

$V(0) = 0$ and $V(L) = V_{ds}$

Resistance of a length dx:

$$dR = \frac{\rho dx}{S} = \frac{dx}{\mu_n qn(x) S}$$ `

$qn(x)S$ =Charge per unit length in x direction= $WQ_n(x)$

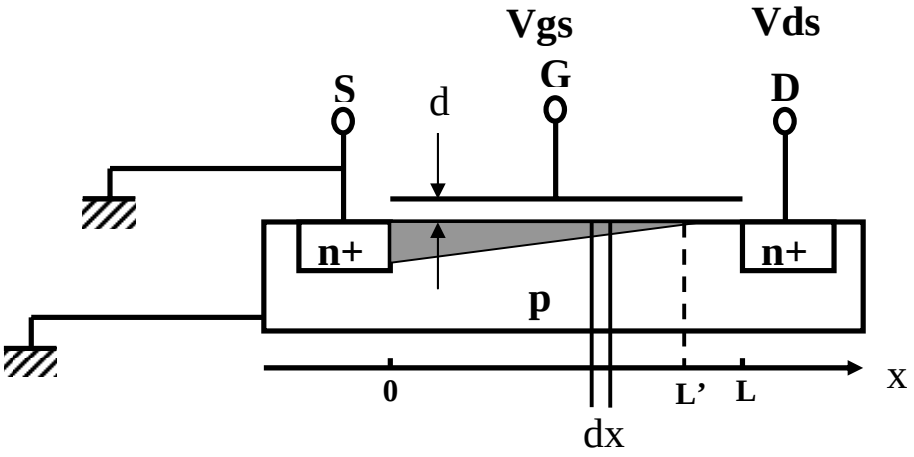
$$dR = \frac{dx}{\mu_n Q_n(x) W}$$

$$dV = I_D dR$$

$$\int_0^{Vds} \mu_n W C_{ox}(V_{gs} - V_{TH} - V(x))dV = \int_0^{L} I_d dx$$

$$I_d = \frac{W}{L}\mu_n C_{ox}\left[(V_{gs} - V_{TH})V_{ds} - \frac{{V_{ds}}^2}{2}\right]$$

Saturation Mode (Pinch-Off)



$$qn(x) = C_{ox}(V_{gs} - V_{TH} - V(x)) \quad qn(L) = C_{ox}(V_{gs} - V_{TH} - V_{ds})$$

For $V_{ds} \geq V_{gs} - V_{TH} = V_{dssat}$, $n(L) = 0$: the channel is pinched-off near the drain

Further increase of V_{ds} doesn't increase the source-drain current

$$\int_0^{Vdssat} W\mu_n C_{ox}(V_{gs} - V_{TH} - V(x))dV = \int_0^{L'} I_d dx$$

$$I_d = \frac{W}{2L'}\mu_n C_{ox}(V_{gs} - V_{TH})^2 \cong \frac{W}{2L}\mu_n C_{ox} {V_{dssat}}^2 \equiv I_{dsat}$$