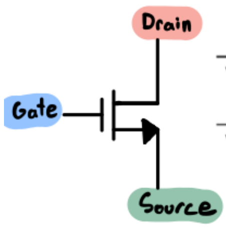
Basic MOS Device Physics:

NMOS:

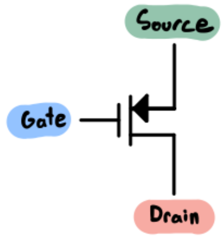


	NMOS
V_G high	Device is ON D is shorted to S
V_G low	Device is OFF D & S are disconnected

Current flows from Drain to Source

$$\text{Source} \xrightarrow{\text{electron}} \text{Drain}$$

PMOS:



	PMOS
V_G high	Device is OFF D & S are disconnected
V_G low	Device is ON D is shorted to S

Current flows from Source to Drain

$$\text{Source} \xrightarrow{\text{hole}} \text{Drain}$$

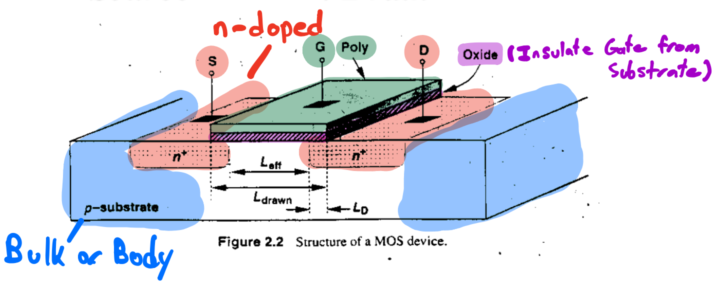
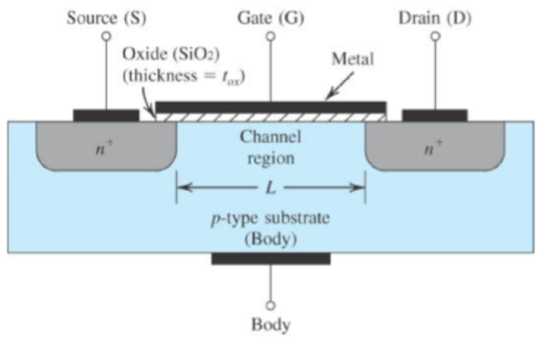


Figure 2.2 Structure of a MOS device.



Threshold Voltage:

- The voltage V_{th} such that the device is ON if $V_G > V_{th}$

Analytically:

$$V_{TH} = \Phi_{MS} + 2\cdot|\Phi_F| + \frac{|Q_{dep}|}{C_{ox}}$$

Where:

Φ_{MS} = Built-in Potential = $\Phi_{gate} - \Phi_{Silicon}$
= the difference between the work functions of the polysilicon gate and the silicon substrate

Φ_F = Work Function (electrostatic potential) = $\frac{K\cdot T}{q}\cdot\ln\left(\frac{N_{sub}}{n_i}\right)$

Q_{dep} = Charge in the depletion region = $\sqrt{4\cdot q\cdot\varepsilon_{si}\cdot|\Phi_F|\cdot N_{sub}}$

Long-Channel Current:

$$I_D = \mu_n C_{ox}\cdot\frac{W}{L}\cdot\left[(V_{GS}-V_{th})\cdot V_{DS} - \frac{1}{2}V_{DS}^2\right]$$

$$\frac{W}{L} = \text{Aspect Ratio}$$

Regions of Operation:

- $V_{DS} \le V_{GS} - V_{th}$ TRIODE (LINEAR)

Current in Triode Region:

$$I_D = \mu_n \cdot C_{ox}\cdot\frac{W}{L}\cdot\left[(V_{GS}-V_{TH})\cdot V_{DS} - \frac{1}{2}\cdot V_{DS}^2\right]$$

Effective Voltage:

$V_{eff} = V_{GS} - V_{th}$

*Sometimes called Overdrive Voltage

- Small V_{DS}, $V_{DS} \ll 2(V_{GS} - V_{th})$ DEEP TRIODE

The device will behave like a variable resistor

$$I_D = \mu_n \cdot C_{ox} \cdot \frac{W}{L} \cdot (V_{GS} - V_{TH}) \cdot V_{DS}$$

$$R_{ON} = \frac{V_{DS}}{I_D} = \frac{1}{\mu_n \cdot C_{ox} \cdot \frac{W}{L} \cdot (V_{GS} - V_{TH})}$$

- $V_{DS} > V_{GS} - V_{th}$ SATURATION (Active)

channel is pinched off.

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L'} (V_{GS} - V_{TH})^2$$

Summary:

Current Equation for NMOS:

- Current Equation for NMOS:

$$I_D = I_{DS} = \begin{cases} 0 \quad ; if\ V_{GS} < V_{TH}\ (Cut-off) \\ \mu_n \cdot C_{ox} \cdot \frac{W}{L} \cdot (V_{GS} - V_{TH}) \cdot V_{DS} \quad ; if\ V_{GS} > V_{TH}, V_{DS} << 2(V_{GS} - V_{TH})\ (Deep\ Triode) \\ \mu_n \cdot C_{ox} \cdot \frac{W}{L} \cdot \left[(V_{GS} - V_{TH}) \cdot V_{DS} - \frac{1}{2} \cdot V_{DS}^2 \right] \quad ; if\ V_{GS} > V_{TH}, V_{DS} < V_{GS} - V_{TH}\ (Triode) \\ \frac{1}{2} \cdot \mu_n \cdot C_{ox} \cdot \frac{W}{L} \cdot (V_{GS} - V_{TH})^2 \quad ; if\ V_{GS} > V_{TH}, V_{DS} > V_{GS} - V_{TH}\ (Saturation) \end{cases}$$

Current Equation for PMOS:

- Current Equation for PMOS:

$$I_D = I_{SD} = \begin{cases} 0 \quad ; if\ V_{SG} < |V_{TH}|\ (Cut-off) \\ \mu_p \cdot C_{ox} \cdot \frac{W}{L} \cdot (V_{SG} - |V_{TH}|) \cdot V_{SD} \quad ; if\ V_{SG} > |V_{TH}|, V_{SD} << 2(V_{SG} - |V_{TH}|)\ (Deep\ Triode) \\ \mu_p \cdot C_{ox} \cdot \frac{W}{L} \cdot \left[(V_{SG} - |V_{TH}|) \cdot V_{SD} - \frac{1}{2} \cdot V_{SD}^2 \right] \quad ; if\ V_{SG} > |V_{TH}|, V_{SD} < V_{SG} - |V_{TH}|\ (Triode) \\ \frac{1}{2} \cdot \mu_p \cdot C_{ox} \cdot \frac{W}{L} \cdot (V_{SG} - |V_{TH}|)^2 \quad ; if\ V_{SG} > |V_{TH}|, V_{SD} > V_{SG} - |V_{TH}|\ (Saturation) \end{cases}$$