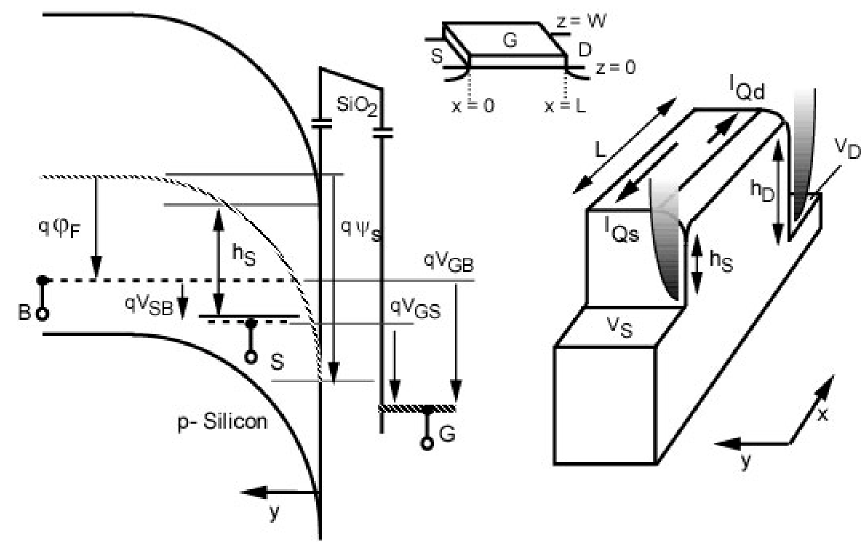
TECHNOLOGY AN DEVICES

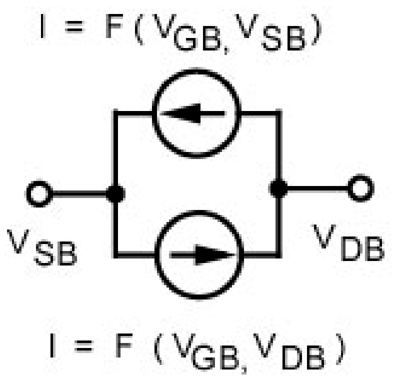
MOS TRANSISTOR

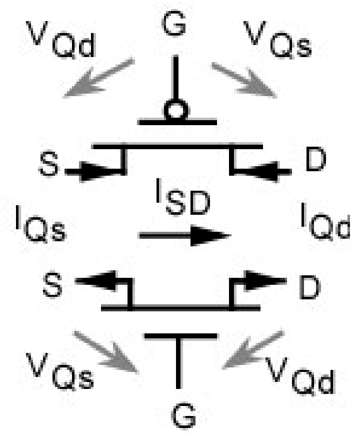


$$I \equiv I_{Q_S} - I_{Q_D} =$$

$$\mu \frac{W}{L}\left[\left(\frac{1}{2}\frac{{Q_S}^2}{C_{ox}+C_{dep}} + \frac{kT}{q}Q_S\right) - \left(\frac{1}{2}\frac{{Q_D}^2}{C_{ox}+C_{dep}} + \frac{kT}{q}Q_D\right)\right]$$

SYMMETRIC MOS EQUATIONS



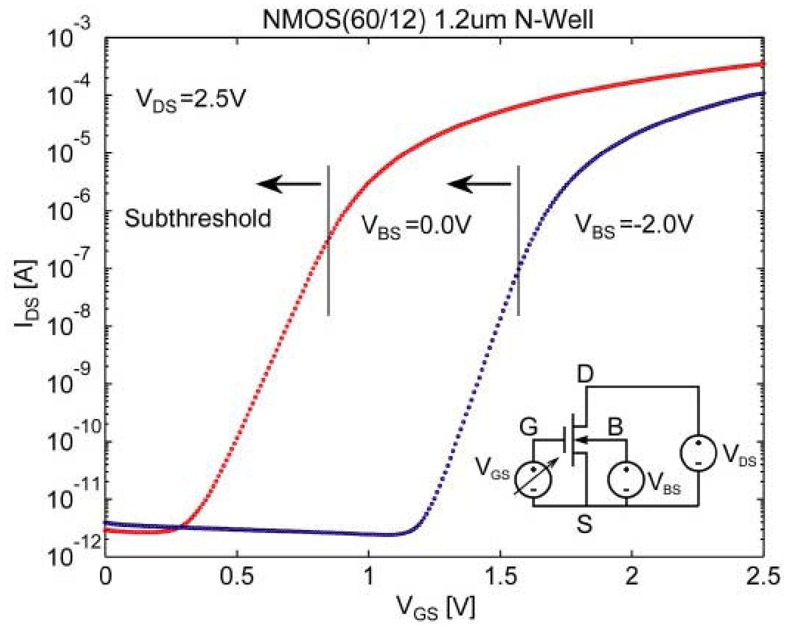


$$I_{SD} \propto F\left(V_{GB}, V_{SB}\right) - F\left(V_{GB}, V_{DB}\right)$$

SUBTHRESHOLD REGION

$$\boxed{I_{SD} \propto G\left(V_{GB}\right)\left[H\left(V_{SB}\right) - H\left(V_{DB}\right)\right]}$$

MOS CHARACTERISTICS



- Subthreshold/Weak inversion - exponential law-
- Above threshold -square power law-

MOS IN SUBTHRESHOLD

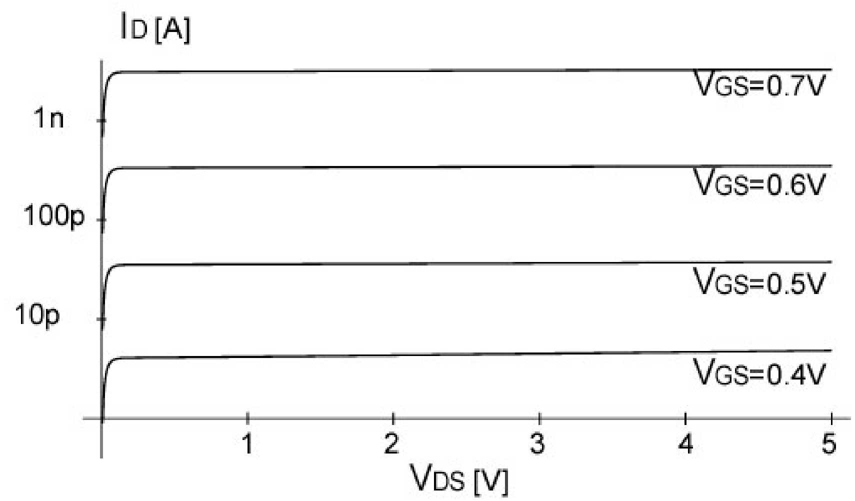
- Current is an exponential function of the terminal voltages Vs, Vb, Vg, Vd
- Large dynamic range
- High gain (transconductance)
- Low saturation voltage Vdsat
- Lossless channel and symmetry between drain and source (diffusive networks)
- Zero conductance control node (gate); possibility of floating gate for long term charge storage
- Mobility considerations
- Frequency limitations (a few MHz)

$$f_{T\max} = \frac{g_m}{2\pi C} \sim \frac{\mu V_t}{\pi L^2}$$

$$1\mu m \rightarrow 100 MHz$$

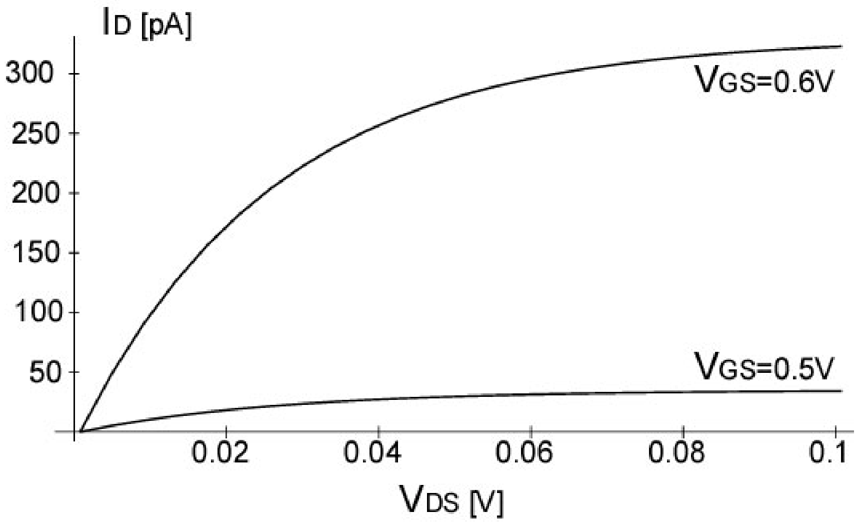
SATURATION CHARACTERISTICS

$$\boxed{\left|I_{Q_D}\right| << \left|I_{Q_S}\right| \rightarrow I \approx I_{Q_S}}$$

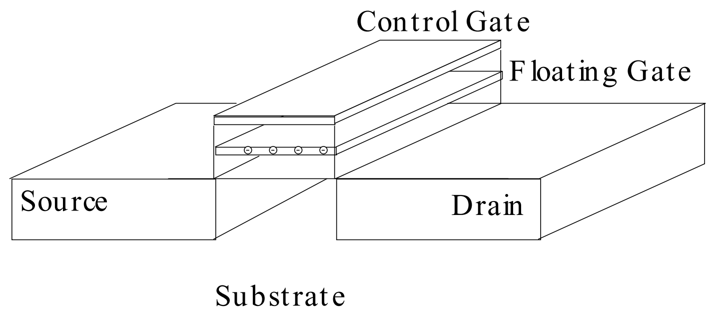


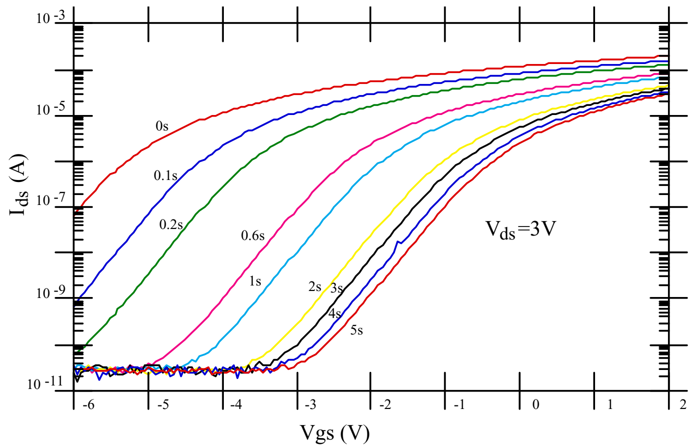
OHMIC CHARACTERISTICS

$$\boxed{I_{Q_D} \approx I_{Q_S} \rightarrow I = I_{Q_S} - I_{Q_D}}$$



FLOATING GATE MOS (FGMOS)

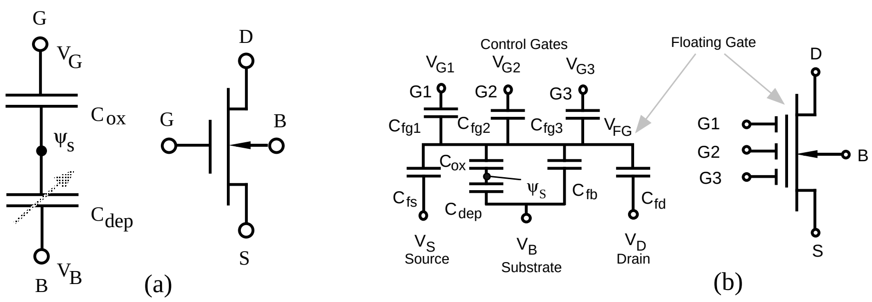




MOS CAPACITANCE MODEL

MOS

FGMOS



$$V_{FG_i} = \frac{Q_{FG_i}}{C_{T_i}} + \sum_{j=1}^{N} \Lambda_{ij} V_{G_j}$$

$$\Lambda_{ij} \equiv \frac{C_{fg_j}}{C_{T_i}}$$

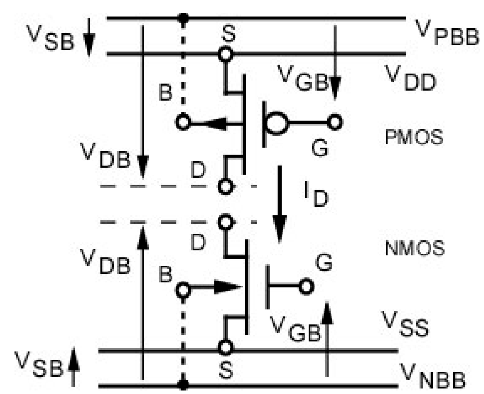
MOS LARGE SIGNAL MODEL

NMOS

$$I_D \equiv I_{DS} = S\, I_{n0} \exp\left(\frac{\kappa_n V_{GB}}{V_t}\right)\left[\exp\left(\frac{-V_{SB}}{V_t}\right) - \exp\left(\frac{-V_{DB}}{V_t}\right)\right]$$

PMOS

$$I_D \equiv I_{SD} = S\, I_{p0} \exp\left(\frac{-\kappa_p V_{GB}}{V_t}\right)\left[\exp\left(\frac{V_{SB}}{V_t}\right) - \exp\left(\frac{V_{DB}}{V_t}\right)\right]$$



$$V_t \equiv \frac{kT}{q} \qquad \kappa \equiv \frac{C_{ox}}{C_{ox} + C_{dep}} \qquad S \equiv \frac{W}{L}$$

MOS SATURATION MODEL

$$I_D \equiv I_{DS} = SI_{n0}\exp\left(\frac{(1-\kappa_n)V_{BS}}{V_t}\right)\exp\left(\frac{\kappa_n V_{GS}}{V_t}\right)$$

$$I_D \equiv I_{SD} = SI_{p0}\exp\left(-\frac{(1-\kappa_p)V_{BS}}{V_t}\right)\exp\left(-\frac{\kappa_p V_{GS}}{V_t}\right)$$

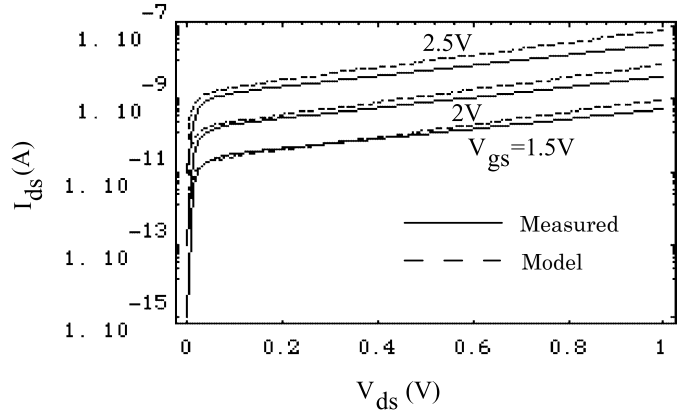
When $V_B = V_S$

$$I_D \equiv S\,I_{n0}\exp\left(\frac{\kappa_n V_{GS}}{V_t}\right)$$

$$I_D \equiv S\,I_{p0}\exp\left(\frac{-\kappa_p V_{GS}}{V_t}\right)$$

Ignoring the Early effect

EARLY EFFECT



$$I_D \equiv I_{DS} = SI_{n0}\exp\left(\frac{(1-\kappa_n)V_{BS}}{V_t}\right)\exp\left(\frac{\kappa_n V_{GS}}{V_t}\right)\left[1+\frac{V_{DS}}{V_O}\right]$$

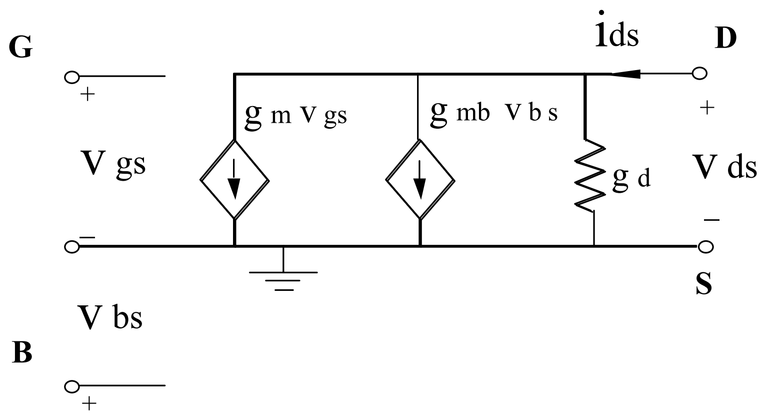
$$I_D \equiv I_{SD} = SI_{p0}\exp\left(-\frac{(1-\kappa_p)V_{BS}}{V_t}\right)\exp\left(-\frac{\kappa_p V_{GS}}{V_t}\right)\left[1+\frac{V_{DS}}{V_O}\right]$$

When $V_B = V_S$

$$I_D \equiv S\,I_{n0}\exp\left(\frac{\kappa_n V_{GS}}{V_t}\right)\left[1+\frac{V_{DS}}{V_O}\right]$$

$$I_D \equiv S\,I_{p0}\exp\left(\frac{-\kappa_p V_{GS}}{V_t}\right)\left[1+\frac{V_{DS}}{V_O}\right]$$

SMALL SIGNAL MODEL
LOW FREQUENCY



Gate transconductance

$$g_m \equiv \frac{\partial I_D}{\partial V_G}\bigg|_{V_B,V_S=c} = \frac{\kappa I_D}{V_t}$$

Backgate transconductance

$$g_{mb} \equiv \frac{\partial I_D}{\partial V_B}\bigg|_{V_G,V_S=c} = \frac{(1-\kappa)\, I_D}{V_t}$$

Source conductance

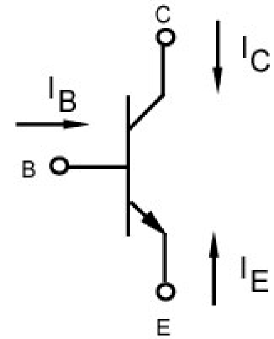
$$g_s \equiv \frac{\partial I_D}{\partial V_S}\bigg|_{V_B,V_G=c} = \frac{I_D}{V_t}$$

Drain conductance

$$g_d \equiv \frac{\partial I_D}{\partial V_D}\bigg|_{V_B,V_G,V_S=c} = \frac{I_D}{V_0}$$

When V_B=V_S then source conductance is the same as gate transconductance

BIPOLAR MODEL



$$I_C = \alpha_F I_{ES}\left(\left(\exp\frac{V_{BE}}{V_t}-1\right)-\frac{1}{\alpha_R}\left(\exp\frac{V_{BC}}{V_t}-1\right)\right)$$

Note: if we could have:

$$\alpha_F = \alpha_R = 1 \rightarrow \; I_C = I_{ES}\left[\exp\frac{V_{BE}}{V_t} - \exp\frac{V_{BC}}{V_t}\right]$$

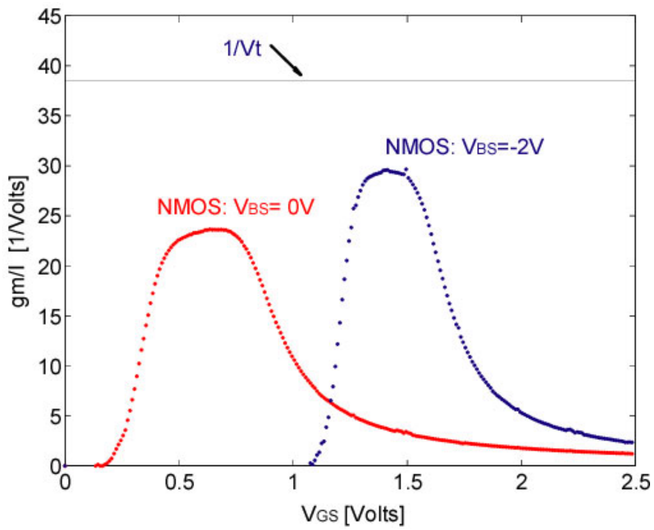
In the linear region:

$$I_C = A_E J_{ES}\left[\exp\left(\frac{V_{BE}}{V_t}\right)-1\right] \approx A_E J_{ES}\exp\left(\frac{V_{BE}}{V_t}\right) \approx I_S\exp\left(\frac{V_{BE}}{V_t}\right)$$

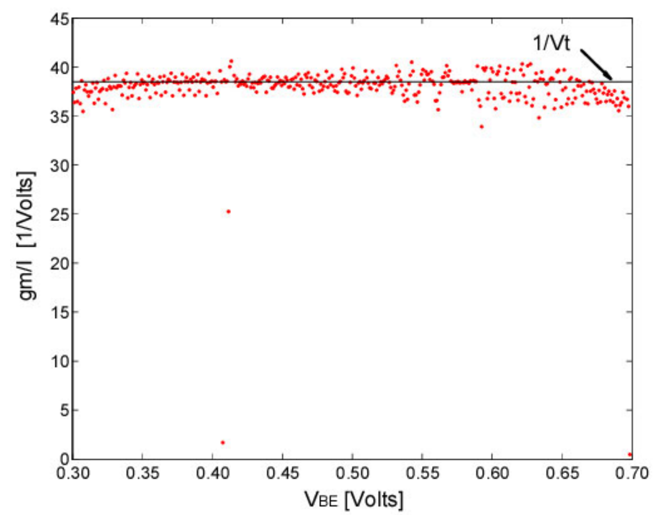
$$I_C = I_S \exp\left(\frac{V_{BE}}{V_t}\right) = I_S \exp\left(\frac{V_B - V_E}{V_t}\right)$$

$$g_m \equiv \frac{\partial I_C}{\partial V_{BE}} = \frac{\partial I_C}{\partial V_B}\bigg|_{V_E=c} = -\frac{\partial I_C}{\partial V_E}\bigg|_{V_B=c} = \frac{I_C}{V_t}$$

NORMALIZED TRANSCONDUCTANCE

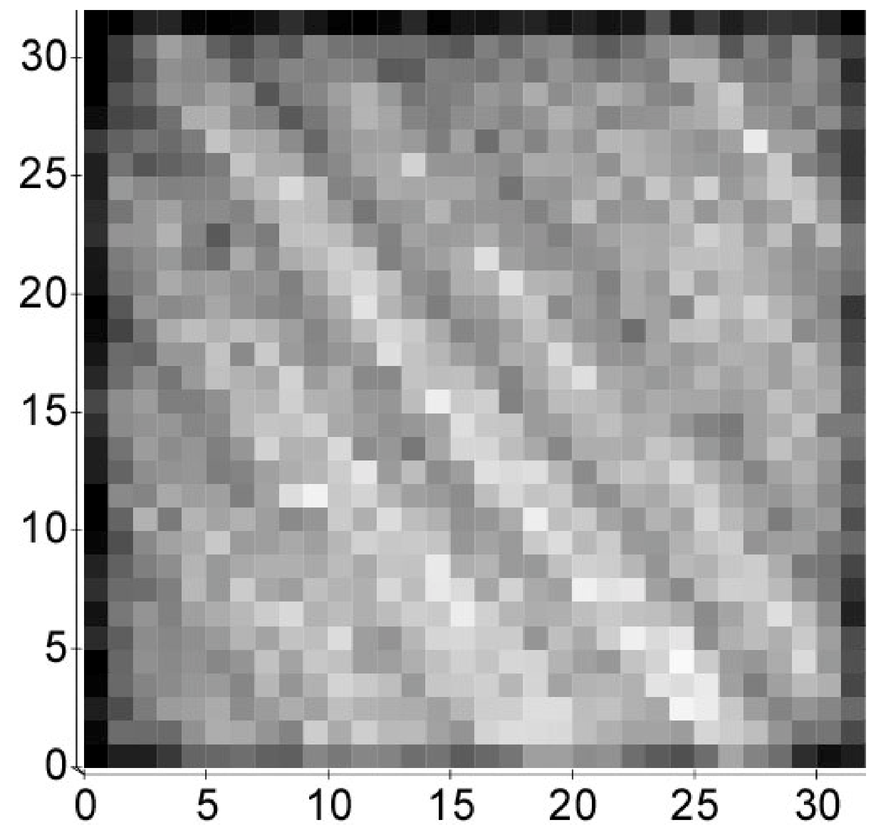


MOS



BJT

MOS MISMATCH



MOS (vs) BIPOLAR