MOSFET

Lec-12 18/03/25

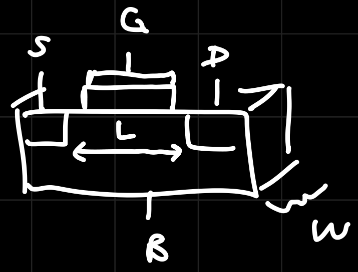
metal oxide semiconductor field effect transistor

4 terminal
- ↳ Gate
- → Drain
- → Source
- → Body

Nmos MOSFET
- ↳ S and D are heavily doped n type
- ↳ p type substrate (body)

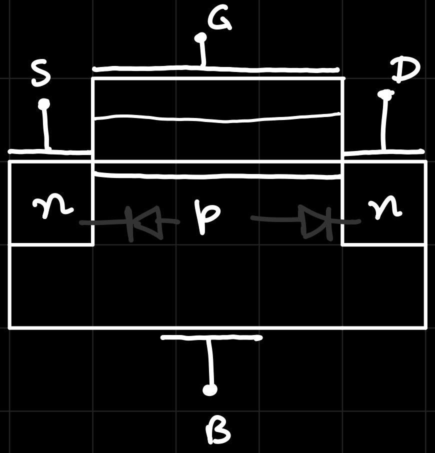
NFET → Nmos
PFET → PMOS

Gate : metal / P-crystalline
2 regions : p type substrate and S, D n^+ type doped
SiO_2 : gate oxide



channel length : L
width : W

L : 0.1 - 3mm | 8nm
W : 0.2 - 100 mm | 0.2-100mm



at equilibrium, no current flows betwen S and D

for inducing a channel btw S and D a positive voltage is applied at Gate terminal : V_{GS}

but still no current flows unless there is a potential difference between S and D

Inversion Layer

for Nmos → free e⁻ due to p type substrate

$V_{GS} > V_T$: threshold voltage for current flow btw S and D

$V_{GS} \uparrow$ → inversion layer width ↑

overdrive voltage : $V_o = V_{GS} - V_T$

enhancement type MOSFET

① Cutoff mode :

$0 < V_{GS} < V_T$

$\sim 0.2 - 0.5V$

assumption: $V_{SB} = 0$

② $0 < V_{GS}$, $V_{GS} > V_T$, $V_{DS} = 0$

enhancement type MOSFET
no current flow
Channel created

③ $0 < V_{GS}$, $V_{GS} > V_T$, $0 < V_{DS} < (V_{GS} - V_T)$

I_D current from D → S flows
proportional to V_{DS} $I_D \propto V_{DS}$

drain current

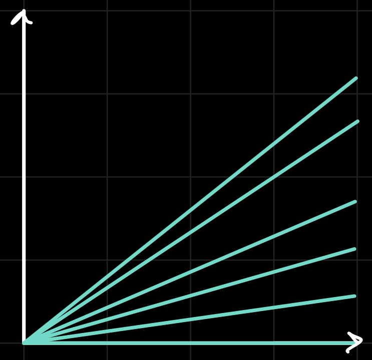
Voltage controlled resistance

triode mode/ linear mode

because of SiO_2 gate oxide → $I_G = 0$

$$R_D = \frac{V_{DS}}{I_D}$$

Characteristic



for small $V_{DS} \rightarrow V_{DS} < V_{GS} - V_T$

triode mode / linear mode

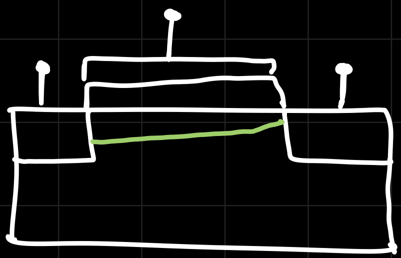
$I_D = 0$

but for $V_{DS} \gg V_{GS} - V_T$

the Gate will attract free e^-

alongside Drain

$I_D \neq 0$

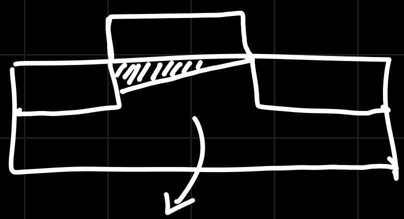


The channel/ inversion layer's width tapers

at very high V_{DS},

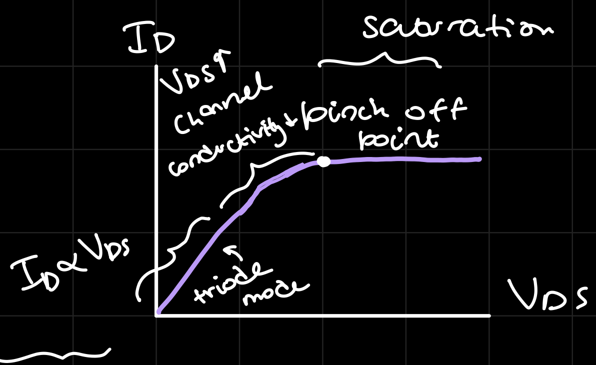
I_D becomes constant

pinch off point situation



pinch off region

no more increase in I_D with V_{DS}



cutoff mode

$I_D = 0$

$V_{GS} - V_T < 0$

$V_c(x)$: channel voltage wrt source at position x

effective voltage inducing the channel at $x \rightarrow \underbrace{V_{GS} - V_T}_{V_0} - V_c(x)$

net charge within narrow dx strip:

$q = CV$

$$dq = -\underbrace{C_{ox}^{\,fm^{-2}}(W\,dx)}_{\substack{\text{(Farad)} \\ \text{net capacitance}}}\underbrace{(V_{GS} - V_T - V_c(x))}_{\text{net potential}}$$

e^- charge (NMOS)

$\bar{E}$ by V_{DS} is in $-x$ direction

$$\bar{E}(x) = \frac{-dV_c(x)}{dx}$$

net mobility constant : μ_n
of charge carriers

$$\text{velocity}\left(\frac{dx}{dt}\right) = \mu_n E(x)$$

$$\frac{-dq}{dt} = \left(\frac{-dq}{dx}\right) \times \left(\frac{dx}{dt}\right)$$

$$I_D(x) = W C_{ox}[V_{GS} - V_T - V_c(x)]\,\mu_n \frac{dV}{dx}$$

at a point x

for the entire channel $\rightarrow$ integrate from $0 \rightarrow L$

$$\int_0^L I_d \, dx = \int_{V=0}^{V=V_{DS}} W C_{ox} [V_{GS} - V_T - V_c(x)] \mu_n \frac{dV_c(x)}{dx} dx$$

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

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

→ at pinch off → $V_{DS} = V_{GS} - V_T$

$$I_{D_{max}} = \frac{1}{2} \mu_n \cdot C_{ox} \cdot \frac{W}{L} [V_{GS} - V_T]^2$$

→ for triode mode: $V_{DS} <<<$

So, $I_D = \mu_n \cdot C_{ox} \cdot \frac{W}{L} [(V_{GS} - V_T) V_{DS}]$

so, $I_D \propto V_{DS}$ $\quad$ V_{DS}^2 term goes away

Ref → Sedra Smith 5th edition
not 7th edition

for small V_{DS}, we see a linear relation btw I_D and V_{DS}

Saturation mode: $V_{DS} \geq V_{GS} - V_T$

$V_{GS} \geq V_T$

MOSFET ≡ Voltage controlled current source AND Voltage controlled resistance