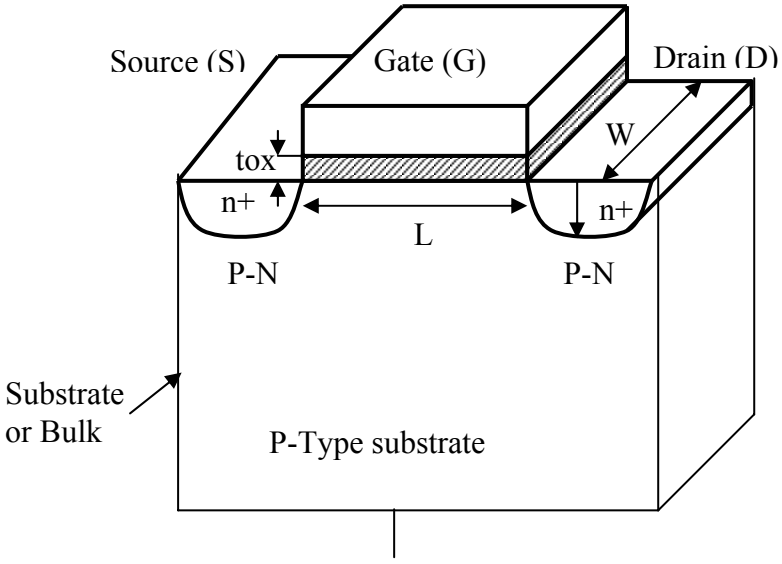
The MOS Transistor (MOSFET)

• Based on the MOS Structure

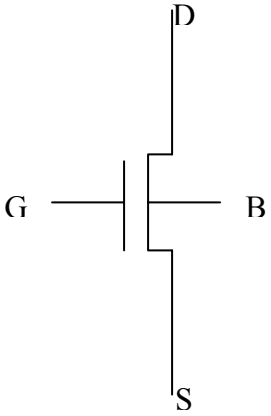
•A Source of carriers is added
- n+ for N-Type MOSFET
- p+ for P-Type MOSFET

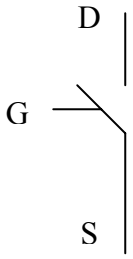
• A Drain is also added



W (channel width)
L (channel Length)

3-D of NMOS Transistor



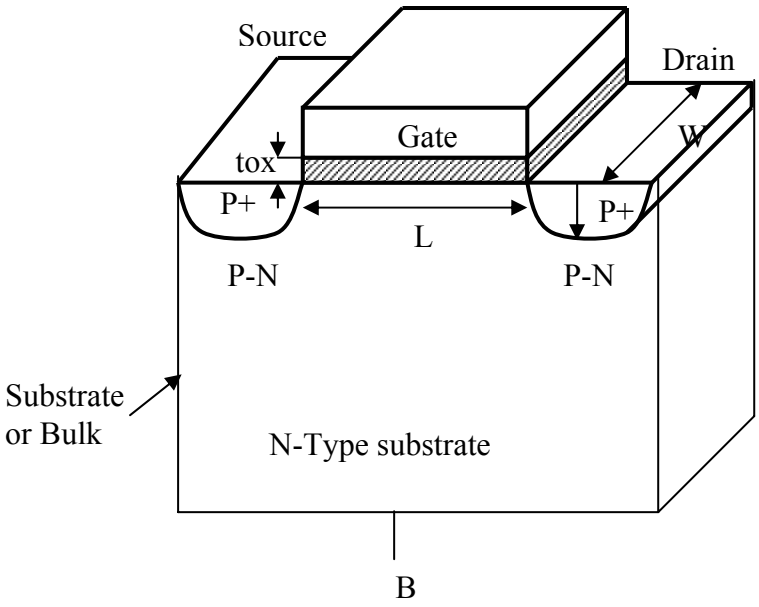


Circuit Symbol

Top View

S n+	G M	D n+

P-Type



3-D of PMOS Transistor

Circuit Symbol

•The MOSFET acts like a switch with no gate bias no current can flow from S/D to D/S ➔ open switch.

•If the appropriate voltage is applied to the gate ➔ causes strong inversion of the substrate surface under the gate ➔ a channel is formed between S & D and current will pass ➔ closed switch.

- For NMOS transistor, the current flows from Drain to Source → hence the Drain is the node with the higher voltage. The source and drain are interchangeable (the node with the higher voltage becomes the drain)

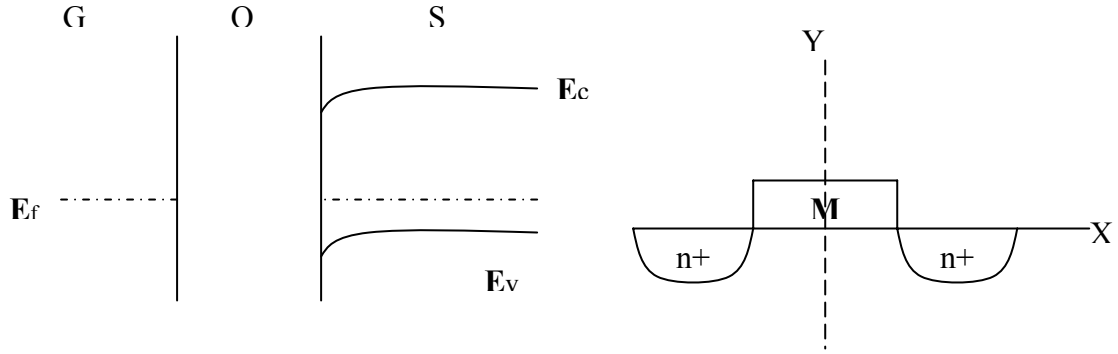
- For PMOS transistor, the current flows from Source to Drain → hence the Source is the node with the higher voltage. The source and drain are also interchangeable (the node with the higher voltage becomes the Source)

Energy Band Diagram fors NMOS Transistor:

•There are 3 regions of operation depending on the NMOS terminal voltages:

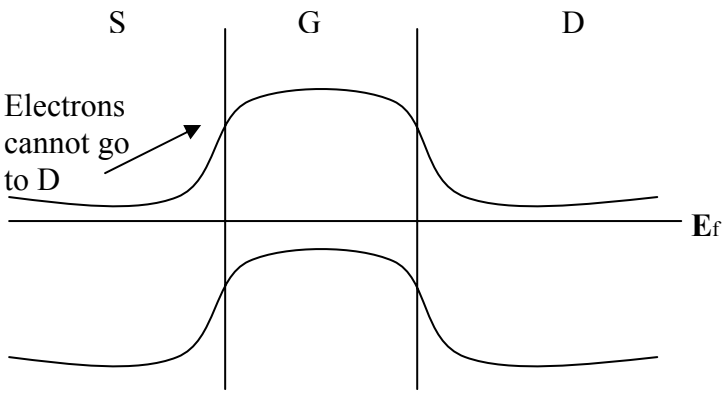
1- If $\mathbf{V}_{GS}$ (Gate to Source voltage) $\leq \mathbf{V}_{th}$ ➔ Cut off ➔ No channel ➔ $\mathbf{I}_{DS}=0$

Vertical Direction (Y-Direction)



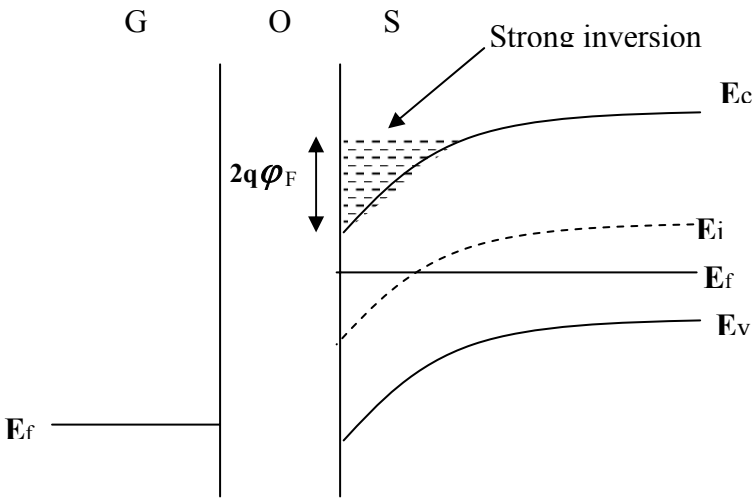
Horizontal Direction (X-Direction)

Zero Bias

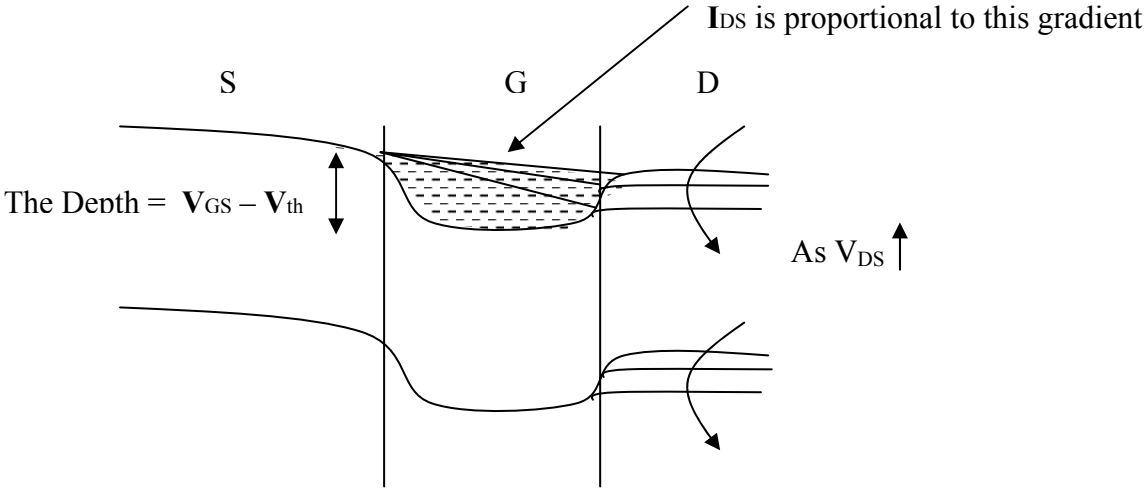


2- If $\mathbf{V}_{GS}$ (Gate to Source voltage $\geq \mathbf{V}_{th}$ and $\mathbf{V}_{DS} < \mathbf{V}_{GS} - \mathbf{V}_{th}$) → Linear region

Vertical Direction (Y-Direction)



Horizontal Direction (X-Direction)



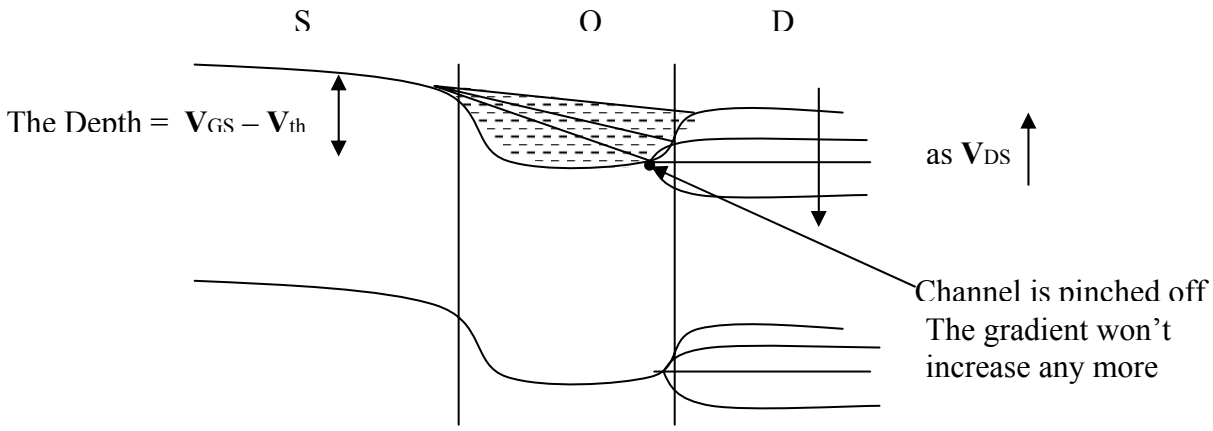
$I_{DS} = \mu_n C_{ox} W/L [(\mathbf{V}_{GS} - \mathbf{V}_{th}) \mathbf{V}_{DS} - 1/2 \mathbf{V}_{DS}^2]$

•The Drain is the node with higher voltage so source and drain are interchangeable.

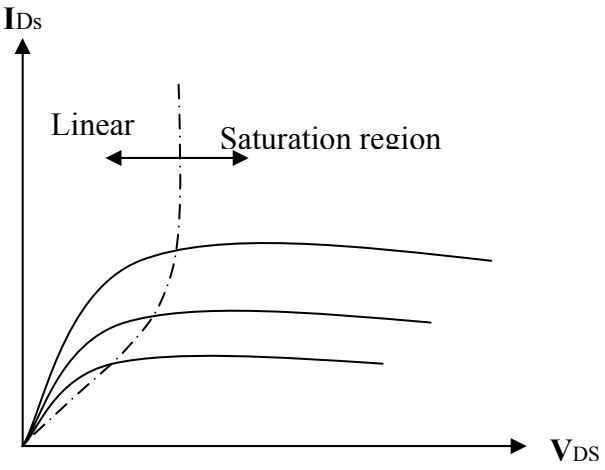
3- If $\mathbf{V}_{DS} \geq \mathbf{V}_{GS} - \mathbf{V}_{th}$

Vertical Direction is same as in linear region above

Horizontal Direction

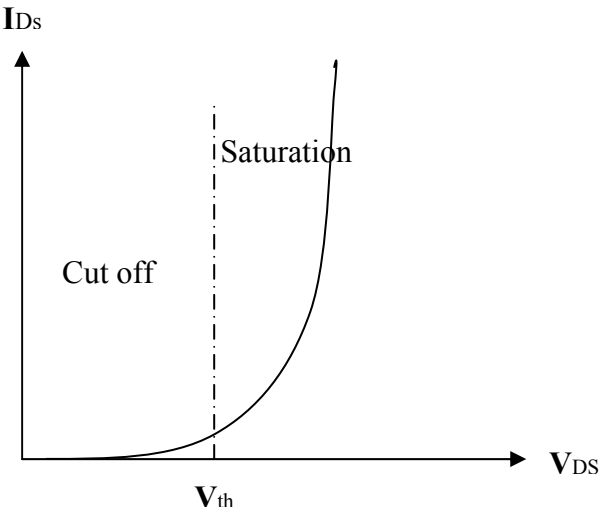


$I_{Dsat} = 1/2\ \mu_n\ Cox\ W/L\ (V_{GS} - V_{th})^2$



Saturation point when $V_{DS} \geq V_{GS} - V_{th}$

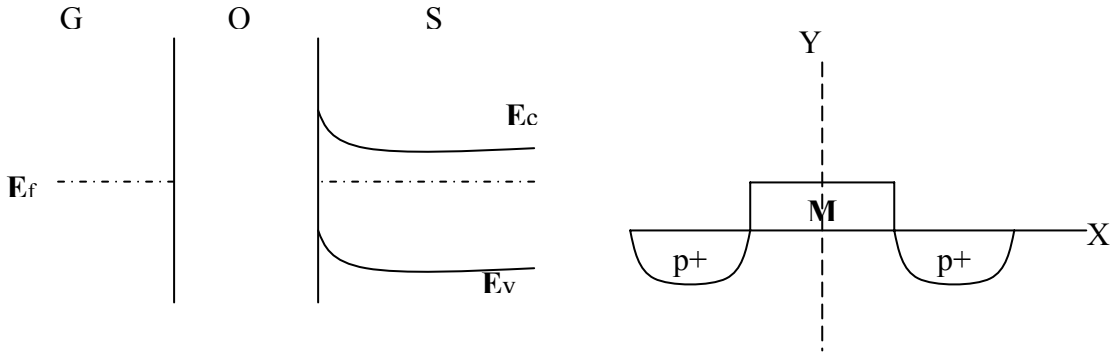
I_{Ds} Versus V_{GS} With $V_{GS} = V_{DS}$



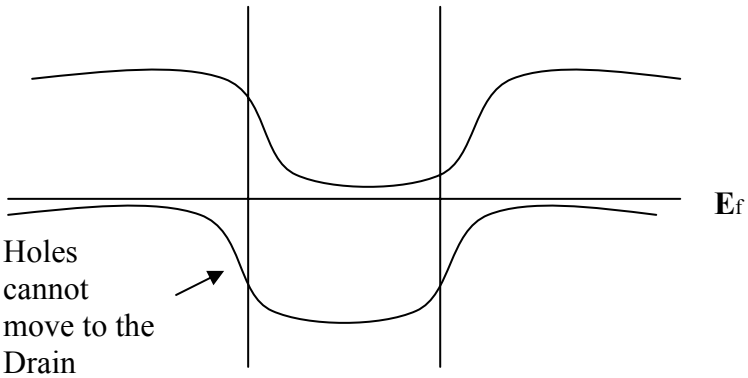
For PMOS:

1. Cut off $V_{SG} \leq |V_{th}|$

Vertical Direction

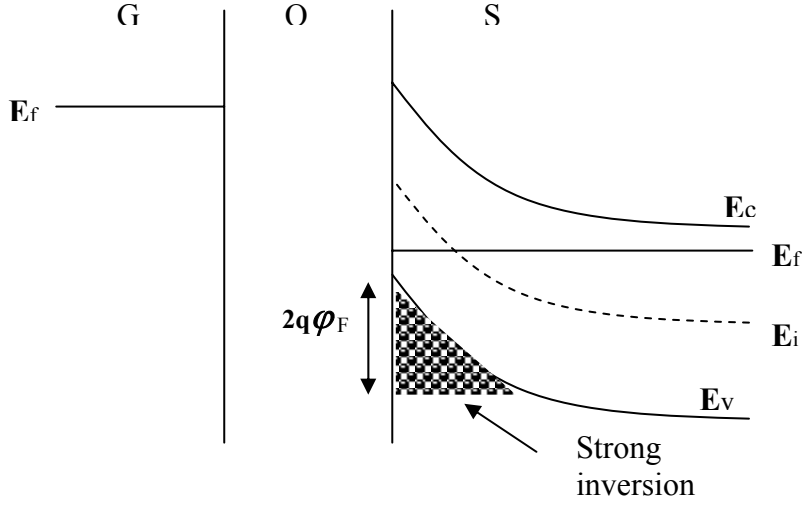


Horizontal Direction

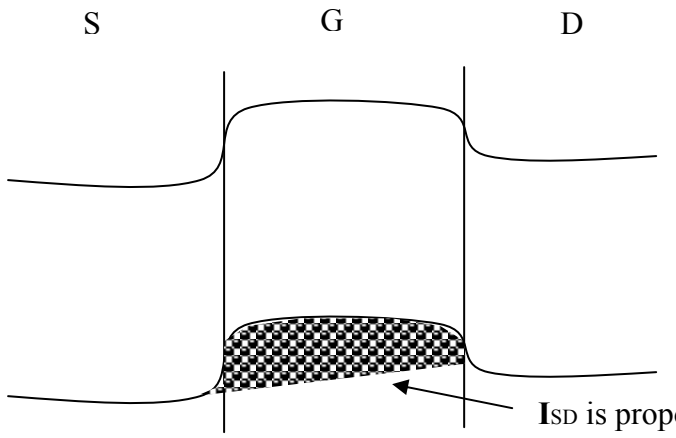


Linear region: $V_{SG} \geq |V_{th}|$ and $V_{SD} < V_{SG} - |V_{th}|$

Y-Direction



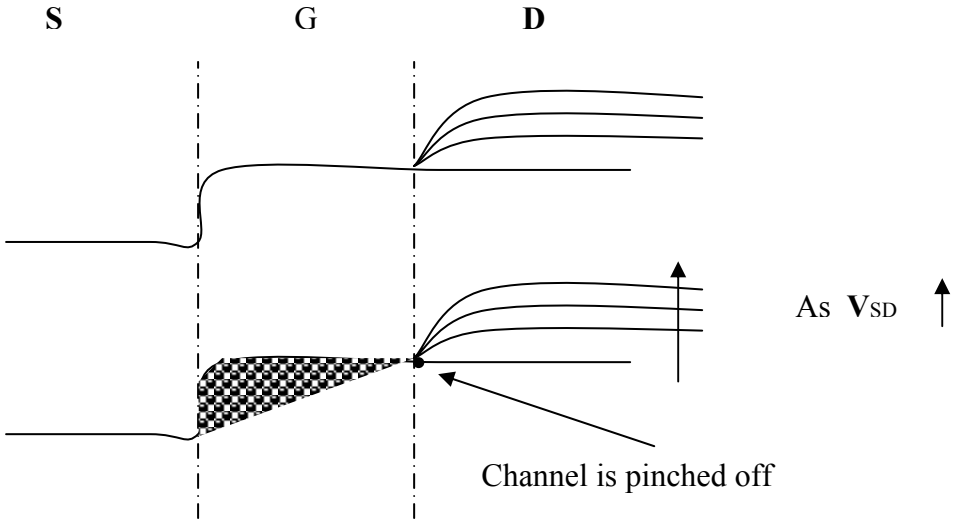
X-Direction



$I_{SD} = \mu_p C_{ox} W/L [(V_{SG} - |V_{th}|) V_{SD} - 1/2 (V_{SD})^2]$

3- Saturation
$V_{SD} \geq V_{SG} - |V_{th}|$

X-Direction



$I_{SDsat} = 1/2\ \mu_p C_{ox} W/L (V_{SG} - |V_{th}|)^2$

• Since in Si $\mu_n = 2$ to 3 μ_p ➔ For the same size , an NMOS transistor would have 2 to 3 times the current of a PMOS transistor.