RAMA UNIVERSITY

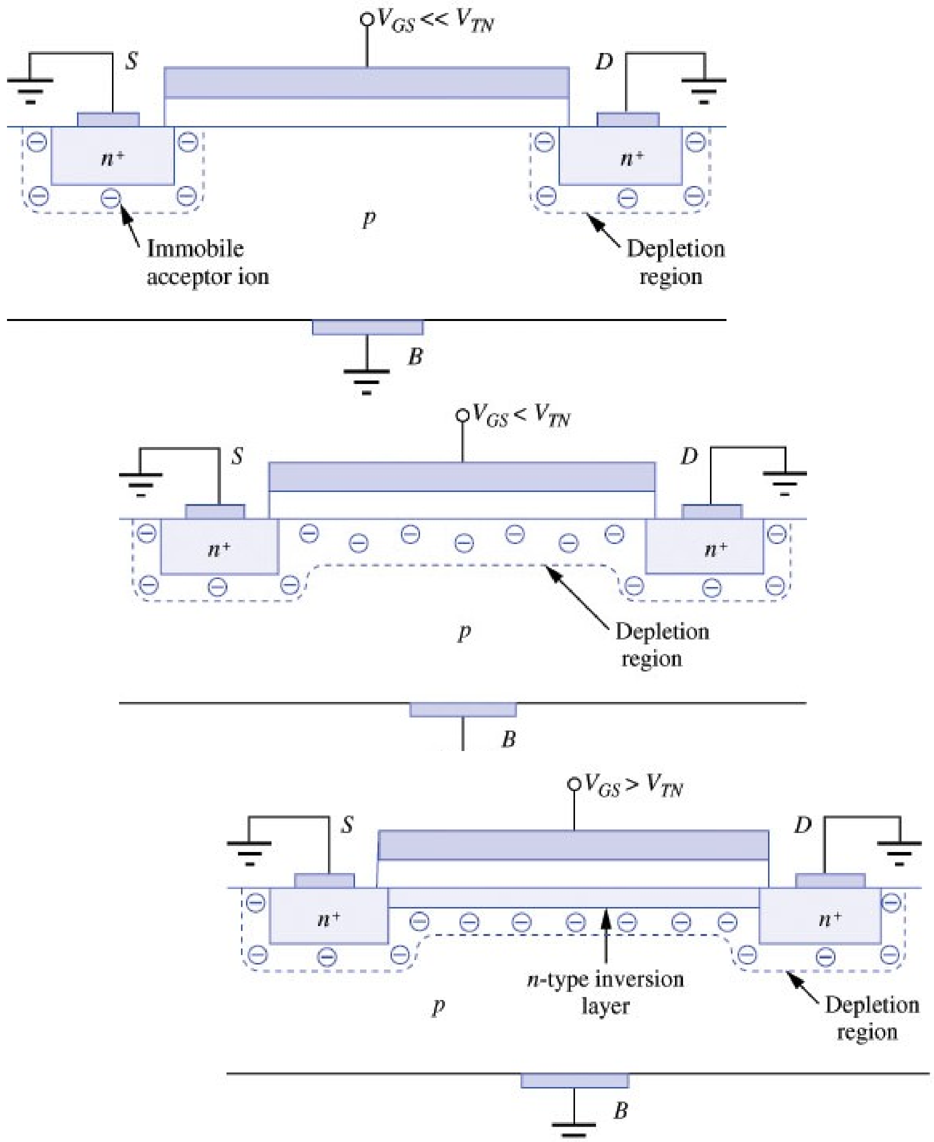
www.ramauniversity.ac.in

FACULTY OF ENGINEERING AND TECHNOLOGY

MEC-022

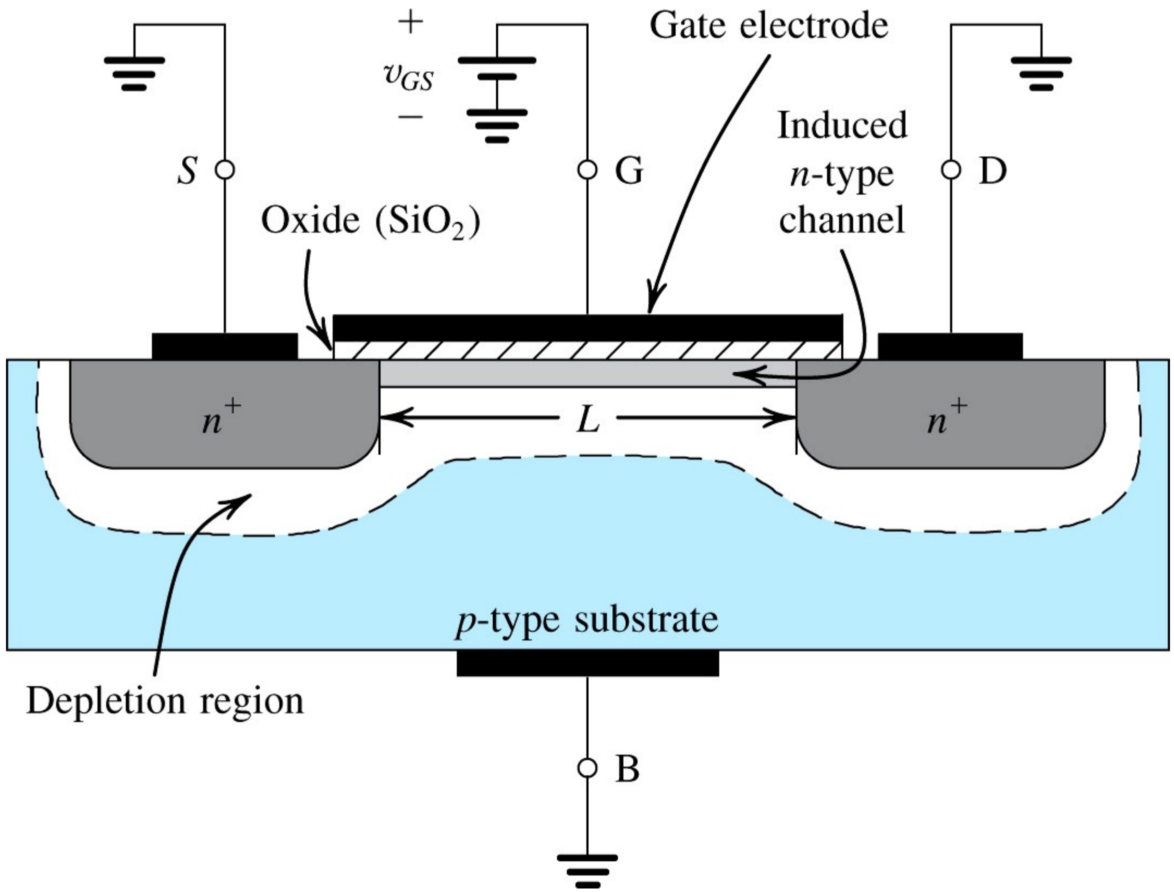
Lecture - 06

NMOS Transistor: Qualitative Behavior @ v_{DS} =0



- $V_{GS} << V_{TN}$ (V_{GS} <0): Two back to back reverse biased *pn* junctions btw S and D. Only small leakage current flows.
- $V_{GS} < V_{TN}$ (V_{GS} >0): Depletion region formed under gate merges with source and drain depletion regions. No current flows between source and drain.
- $V_{GS} > V_{TN}$: Channel is formed between source and drain by **electrons in inversion layer**. If V_{DS}>0, finite i_D flows from drain to source.
- $i_B=0$ and $i_G=0$.

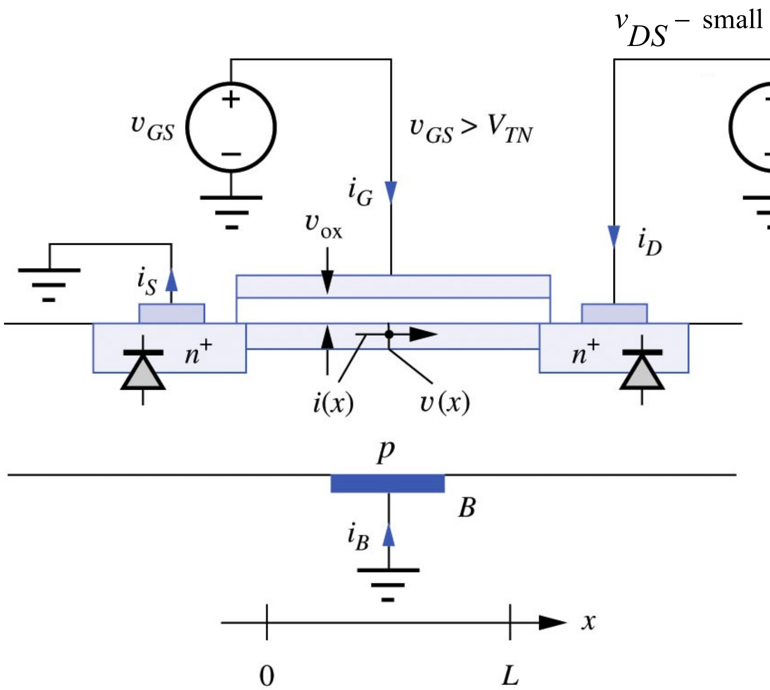
NMOS Transistor: Qualitative Behavior @ v_{DS} =0



Since the induced inversion layer is formed by electrons, it’s called N-channel MOSFET.

NMOS Transistor: Triode Region

Applying a **small** v_{DS} creates a flow of electrons in the induced inversion layer between source and drain - current i_D ($i_D = i_S$, since i_B=0 and i_G=0).



$$i_D = K_n\left(v_{GS} - V_{TN} - \frac{v_{DS}}{2}\right)v_{DS}$$

for $0 \le v_{DS} \le v_{GS} - V_{TN}$

where

$K_n = K_n'W/L$ – *the gain factor*

$K_n' = \mu_n C_{ox}''$ (A/V^2)

$C_{ox}'' = \varepsilon_{ox}/T_{ox}$

ε_{ox} = oxide permittivity (F/cm)

T_{ox} = oxide thickness (cm)

This is the triode region (linear region, ohmic mode).

MOSFET operates like a resistor, controlled by the gate voltage relative to both the source and drain voltages.

N-MOS Transistor: Triode Region (derivation of the source-drain current)

Since currents i_B and i_G both are zero, and there is no path for drain current to escape: $i_S = i_D$.

To find it, we consider the transport of the charge. The linear density of the electron charge at any point in the channel is:

$$Q' = -W\,C_{ox}''(v_{ox} - V_{TN})\ C/\text{cm for}\quad v_{ox} \ge V_{TN},$$

where $C_{ox}'' = \varepsilon_{ox} / T_{ox}$ – oxide capacitance per area, ε_{ox} = oxide permittivity(F/cm), T_{ox} = oxide thickness (cm)

The voltage v_{ox} is the function of position x in the channel: $v_{ox} = v_{GS} - v(x)$. For inversion layer to exist, should be $v_{ox} > V_{TN}$, so $Q' = 0$ until $v_{ox} > V_{TN}$. At the source, $v_{ox} = v_{GS}$ and it decrease to $v_{ox} = v_{GS} - v_{DS}$ at the drain.

The electron drift current is : $i(x) = Q'v_x = \left[-W\,C_{ox}''(v_{ox} - V_{TN})\right](-\mu_n E_x)$ where $E_x = -\dfrac{dv(x)}{dx}$

Combining everything: $i(x) = -\mu_n C_{ox}'' W\left[v_{GS} - v(x) - V_{TN}\right]\dfrac{dv(x)}{dx}$ and integrating:

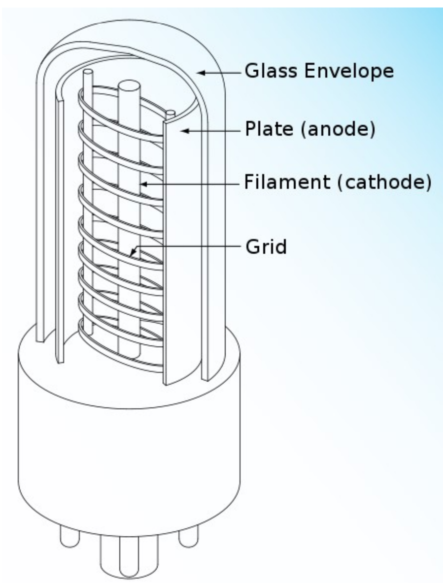
$\int_0^L i(x)dx = -\int_0^{v_{DS}} \mu_n C_{ox}'' W\left[v_{GS} - v(x) - V_{TN}\right]dv(x)$ we get

$$i_D = \mu_n C_{ox}''\frac{W}{L}\left(v_{GS} - V_{TN} - \frac{v_{DS}}{2}\right)v_{DS} = K_n\left(v_{GS} - V_{TN} - \frac{v_{DS}}{2}\right)$$

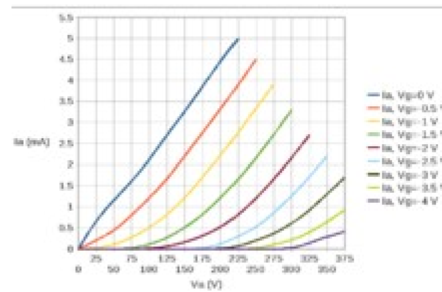
$$\text{where } K_n = K_n'\frac{W}{L},\ \text{ and }\ K_n' = \mu_n C_{ox}''$$

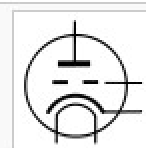
Triode (a bit of history)

A **triode** is an electronic amplification device having three active electrodes. most commonly it's a vacuum tube with three elements: the filament (cathode), the grid (controlling element), and the plate or anode. The triode vacuum tube was the first electronic amplification device. It's *iv*-characteristics was quite linear.



Lee De Forest "Triode" Audion tube from 1908





Schematic symbol for an indirectly heated triode.

N-MOSFET: Triode Region Characteristics

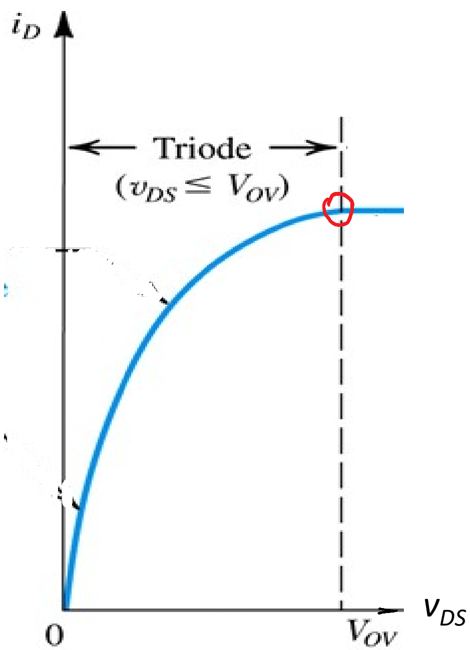
- The expression for i_D is quadratic in v_{DS}

$$i_D = K_n\left(v_{GS} - V_{TN} - \frac{v_{DS}}{2}\right)v_{DS}$$

N-MOSFET: Triode Region Characteristics

- The expression for i_D is quadratic in v_{DS} with max reached at $v_{DS} = v_{GS} - v_{TN} = v_{OV}$

$$i_D = K_n\left(v_{GS} - V_{TN} - \frac{v_{DS}}{2}\right)v_{DS}$$




Thank You!