NMOS Transistor

Instructor – Dr. Madhav Rao

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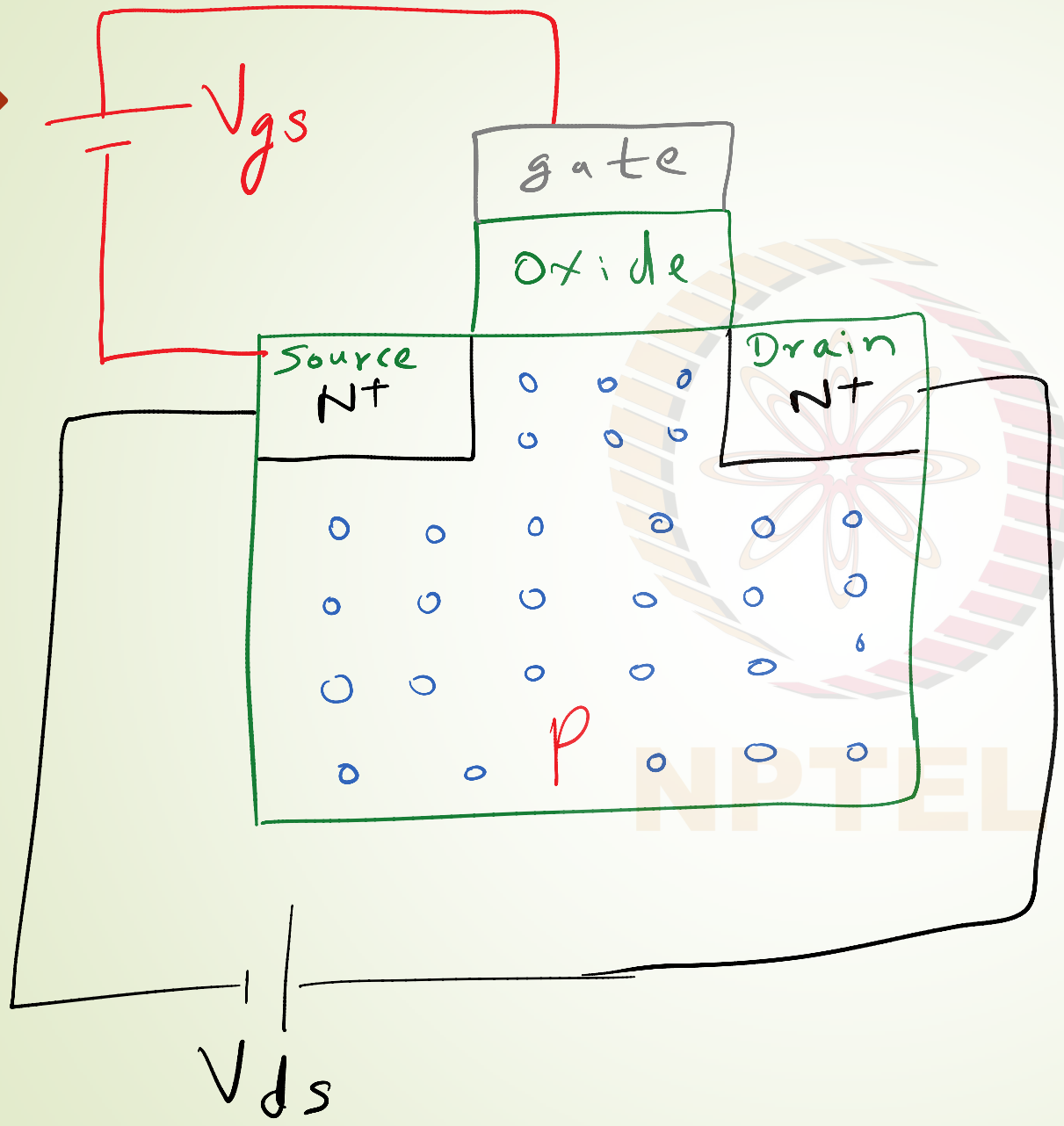


$V_{gs} < 0$

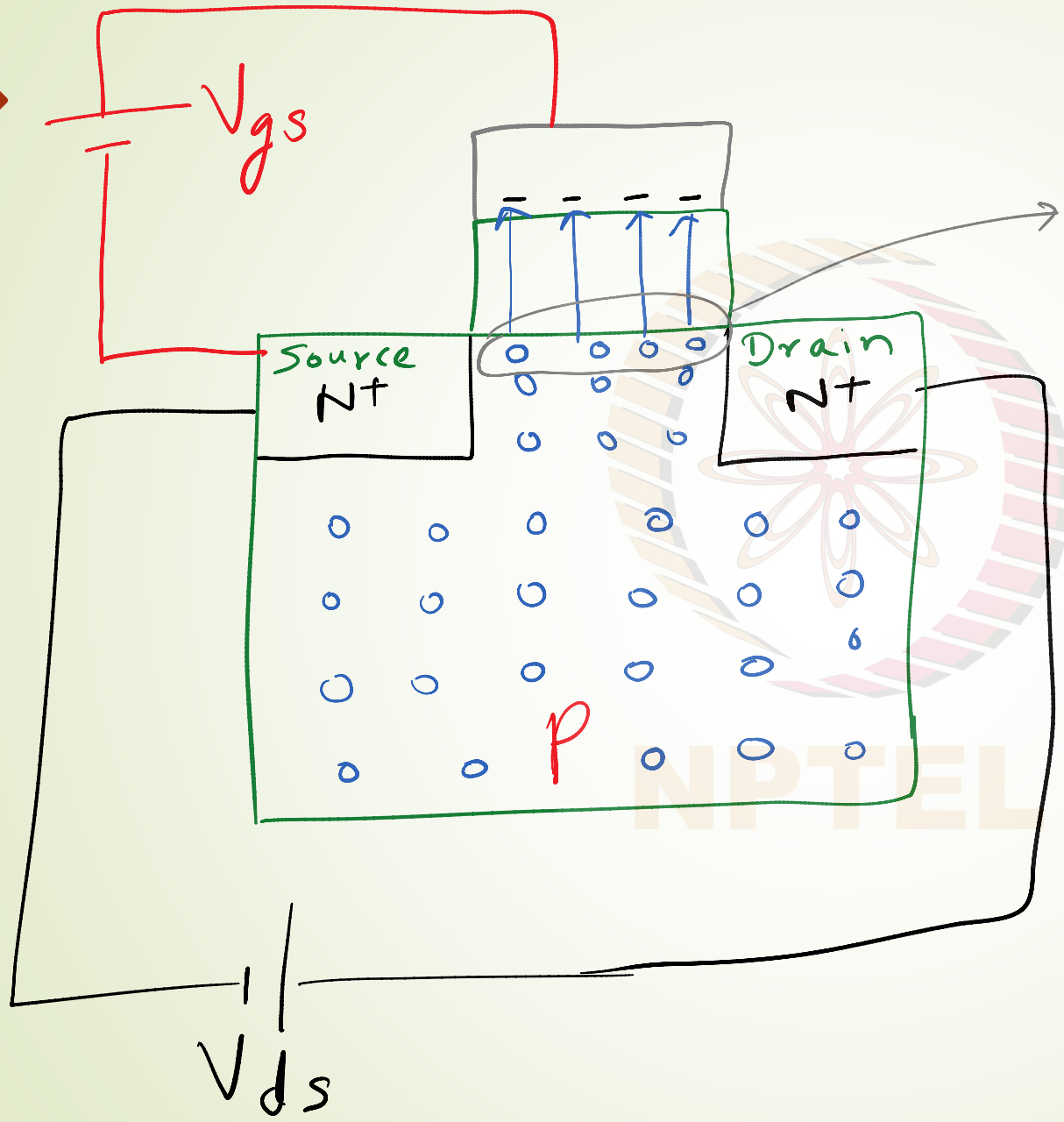
Accumulation mode

$0 < V_{gs} < V_t$

Depletion Mode

$V_{gs} > V_t$

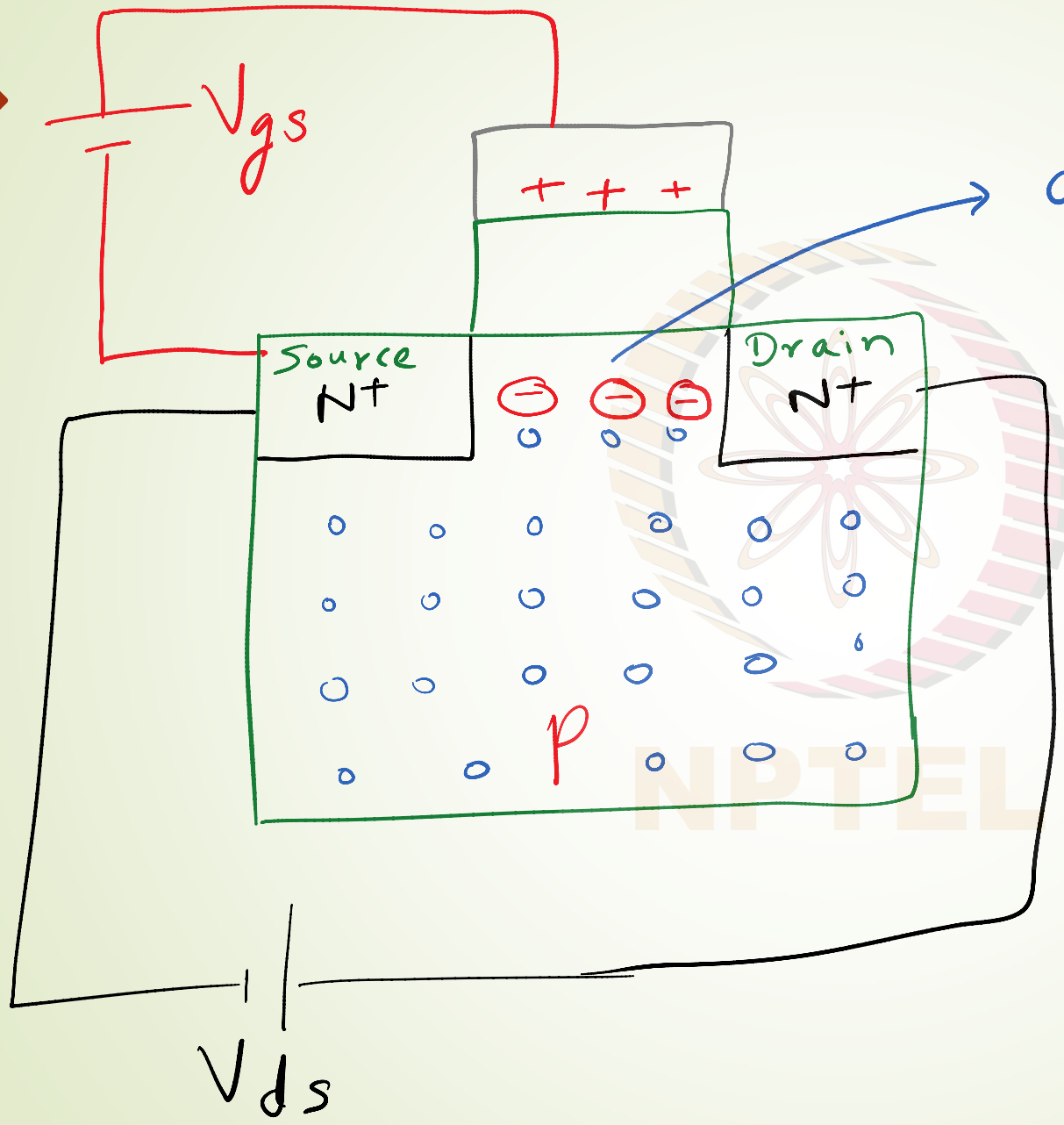
Inversion mode



Accumulated

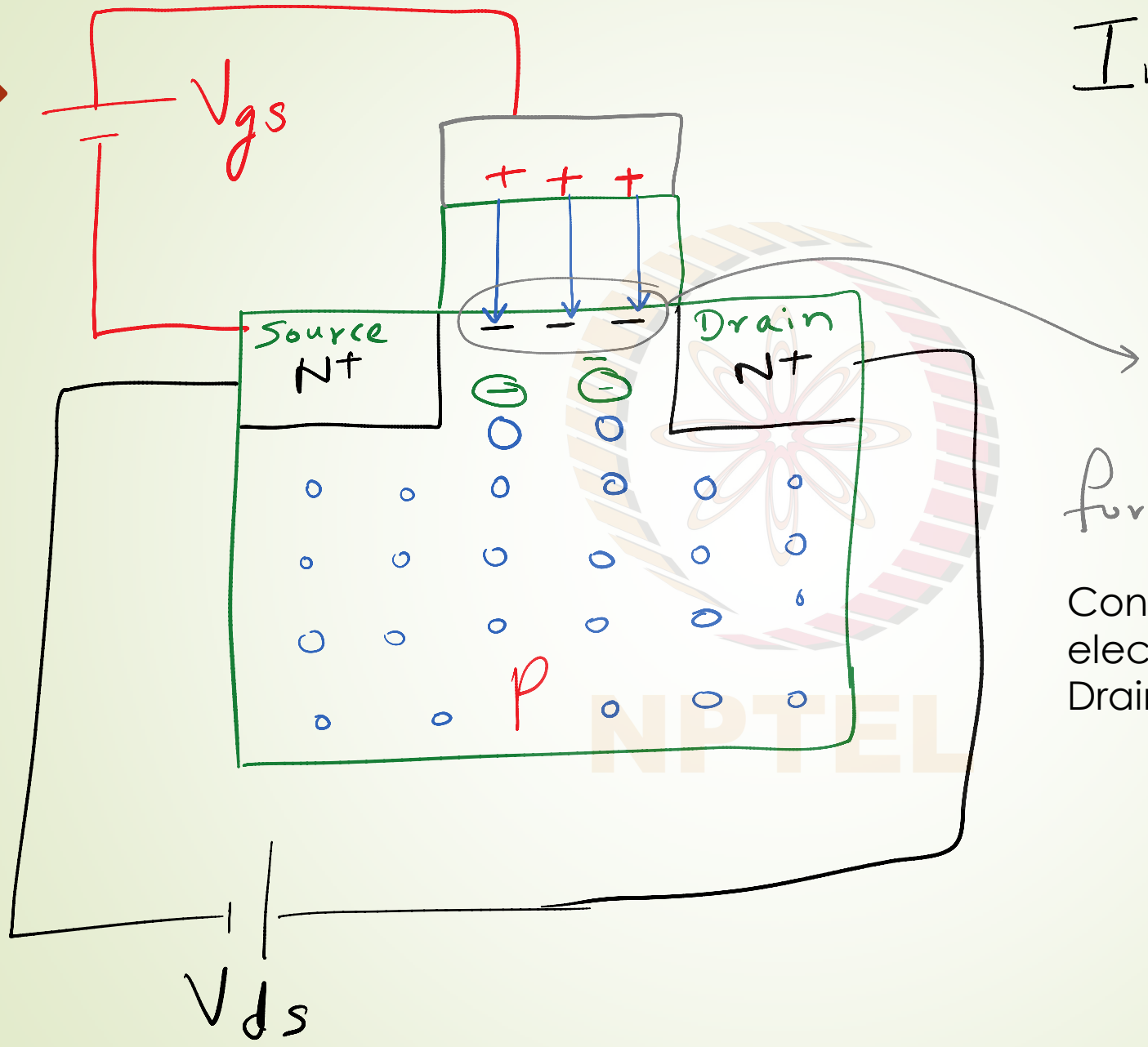
$V_{gs} < 0$

Accumulation Mode



depletion mode

$V_t > V_{gs} > 0$

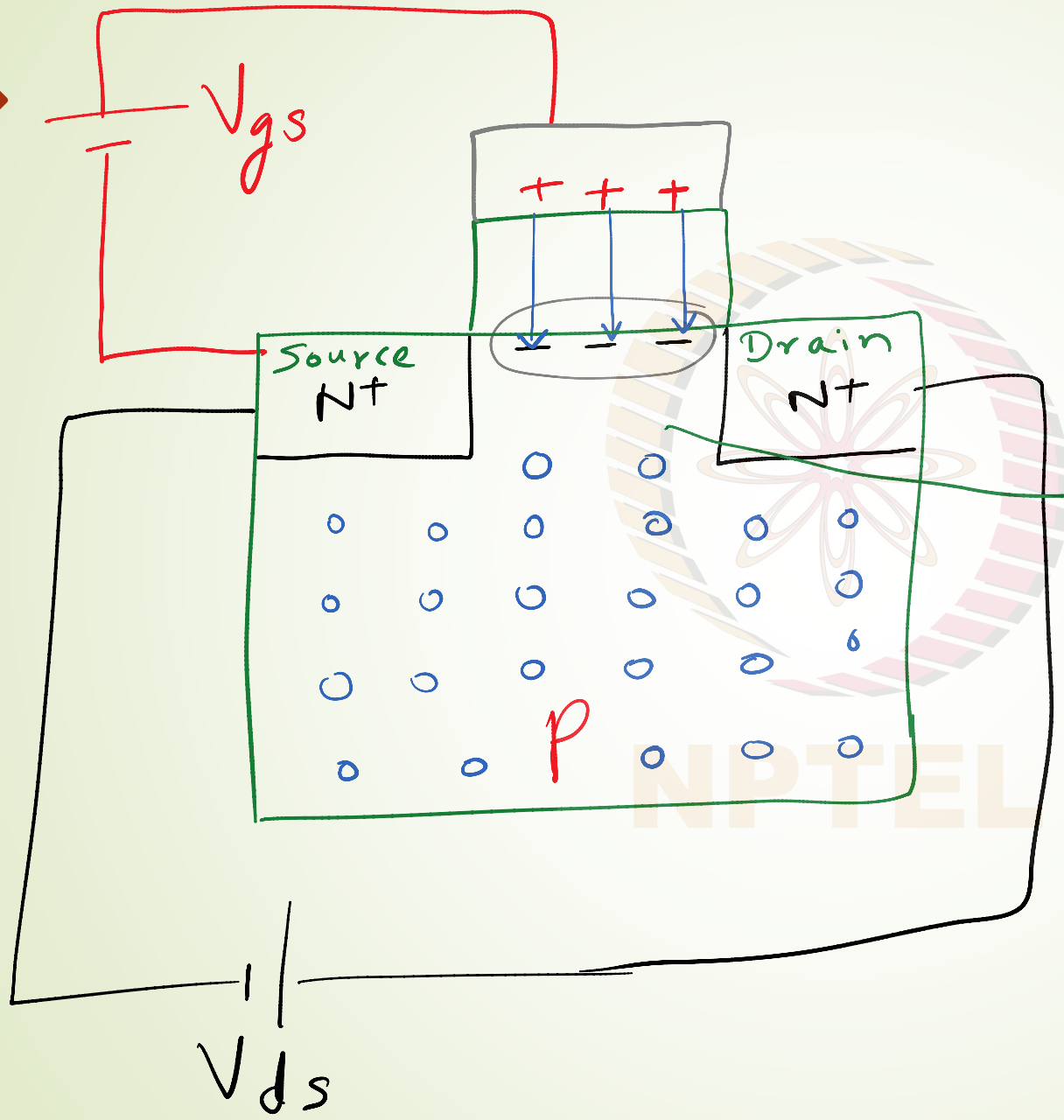


Inversion Region

$V_{gs} > V_t$

Minority carriers form conducting path.

Conducting path allows free electrons to move from Source to Drain leading to I_{ds}



Inversion Region

$V_{gs} > V_t$

V_t depends on Dopant concentration & thickness oxide

→ Depletion Region

Case 1: $V_{ds} > 0$,
Ids increases with increase in V_{ds} & V_{gs}.

Case 2: Vds >> 0,
Vd >> Vs, Vgd << Vgs

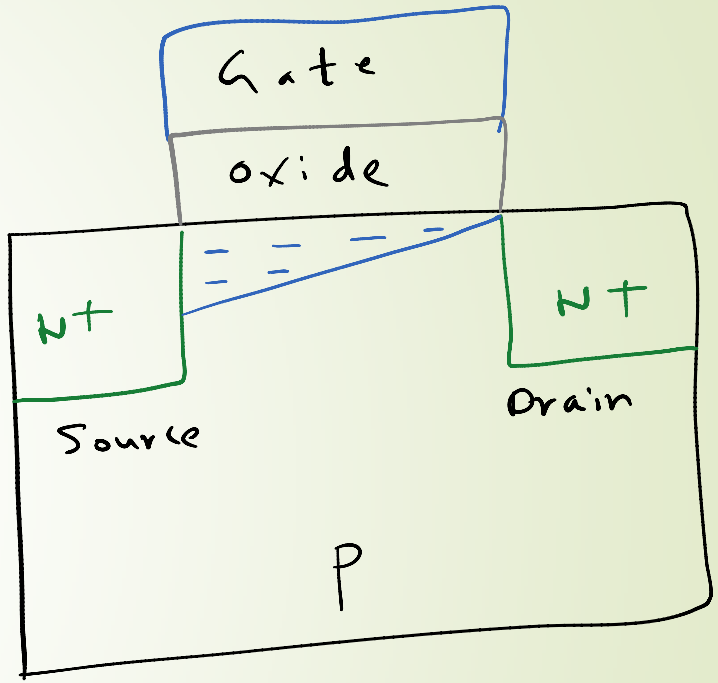
For example:
Vgs = 1.0V, V_T = 0.3V,
Vds = 0.71V,

Then Vgs = 1.0V, Vgd = 0.29V

The channel is no longer inverted at Drain side and this is called **pinch off region** also called as **saturation region.**

Current (Ids) still flows due to drift of electrons under the influence of +ve drain voltage.
But an increase in Vds saturation-region, does not increase Ids.

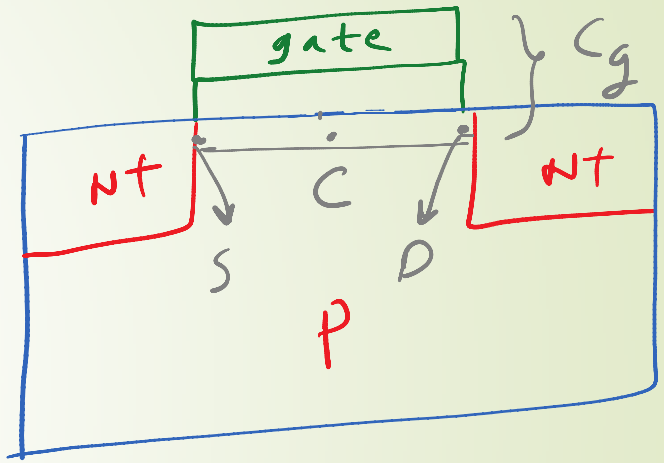
Ids remains constant for $\mathbf{V_{ds} > = V_{gs} - V_t}$

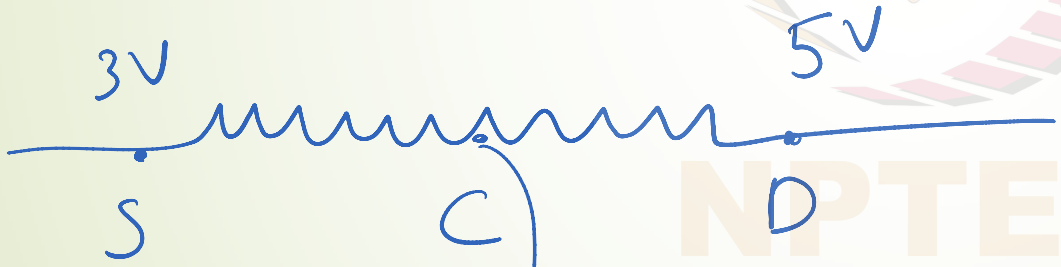


$$Q = C\,V$$

$$Q_{channel} = C_g\left(V_{gc} - V_t\right)$$

$$Q_{channel} = C_g\left(V_g - \left(\frac{V_s + V_d}{2}\right) - V_t\right)$$





$$4V = \frac{3+5}{2}$$

Linear Resistor Model

$$Q_{channel} = C_g\left(V_{gs} - \frac{V_{ds}}{2} - V_t\right)$$

$$C_g = \frac{k_{ox}\,\varepsilon_0\,WL}{t_{ox}} = \varepsilon_{ox}\frac{WL}{t_{ox}} = C_{ox}\,WL$$

$$I_{ds} = \frac{Q_{channel}}{time} \qquad \frac{L}{v} = \frac{L}{\mu E_{ds}} = \frac{L^2}{\mu V_{ds}}$$

$$I_{ds} = \frac{C_{ox}\,WL}{\frac{L^2}{\mu V_{ds}}}\left(V_{gs} - V_t - \frac{V_{ds}}{2}\right)$$

$$\boxed{I_{ds_{Linear}} = \mu C_{ox} \frac{W}{L} \left(V_{gs} - V_t - \frac{V_{ds}}{2} \right) V_{ds}}$$

$$I_{ds} = \beta \left(V_{gs} - V_t - \frac{V_{ds}}{2} \right) V_{ds}$$

During saturation, $V_{ds} = V_{gs} - V_t$

$$\boxed{I_{ds_{sat}} = \frac{\beta}{2} \left(V_{gs} - V_t \right)^2}$$

Example: $\frac{W}{L} = \frac{4}{2}$, $t_{ox} = 1.05\,nm$, $V_t = 0.3V$

$\mu = 80\,cm^2/V\text{-}sec$

$$\beta = \mu C_{ox} \frac{W}{L} = 80 \times \frac{8.854 \times 10^{-14}\,F/cm \times 3.9}{1.05 \times 10^{-7}\,cm} \times \frac{4}{2}$$

$$\boxed{\beta = 5.26 \times 10^{-4}}$$

$$I_{ds_{sat}} = \frac{\beta}{2}(1 - 0.3)^2 = 128.9\,\mu A$$