Body Effect:

Normally, substrate and source are connected (grounded)

But if source is not grounded, the threshold voltage is not 1V. It follows the following equation

$$V_t = V_{to} + \gamma \sqrt{V_{sb}}$$

where

$V_{sb} = V_s - V_b$

V_s → source, V_b → substrate

γ = constant = 0.3 to 0.7

Example: If source terminal = 1V, substrate = 0V,

Then
$$V_t = V_{to} + \gamma \sqrt{V_{sb}}$$
$$= 1 + 0.5\sqrt{1-0}$$
$$= 1.5\,V$$

2.4 I_{ds} vs V_{ds} characteristics of NMOS

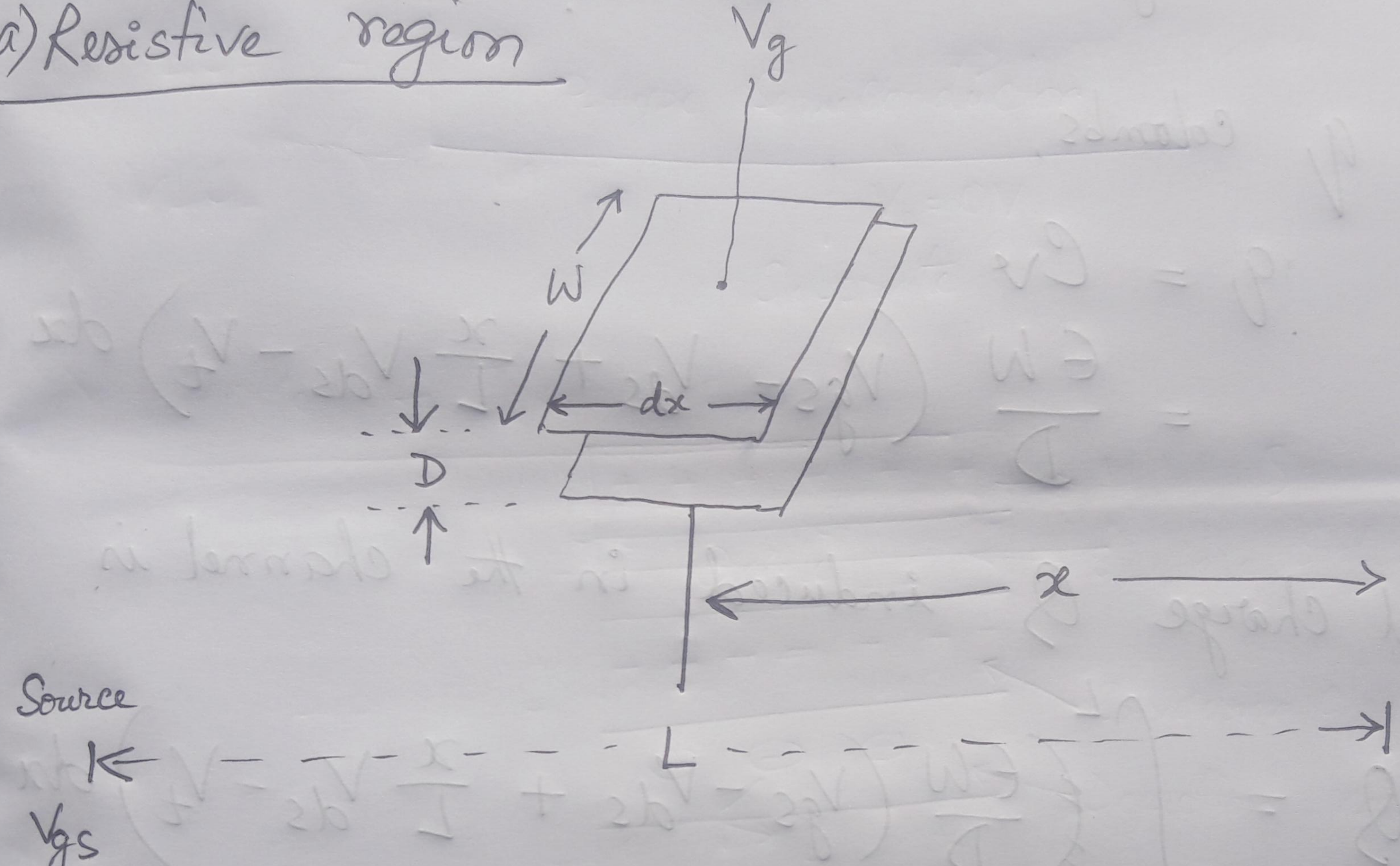
* When $V_{gs} < V_t$, the transistor (NMOS) is off.
So no current flow (regardless of V_{ds})

* But if $V_{gs} > V_t$, NMOS conducts

a) Resistive region, when $V_{ds} < V_{gs} - V_t$

b) Saturation region, when $V_{ds} \geq V_{gs} - V_t$

a) Resistive region



The channel width $= W$

length $= L$

Depth $= D$

Let us consider these capacitances of length dx situated at distance x from drain terminal.

$$C = \frac{\epsilon \cdot \text{Area}}{\text{Thickness}}$$

ϵ = permittivity of insulator

$$= \frac{\epsilon\,(W \cdot dx)}{D}$$

The voltage v in excess of V_t across the capacitor is

$$v = \left(V_{gd} + \frac{x}{L} V_{ds}\right) - V_t$$

$$= V_{gs} - V_{ds} + \frac{x}{L} V_{ds} - V_t$$

Charge q colombs,

$$q = Cv$$

$$= \frac{\epsilon W}{D} \left(V_{gs} - V_{ds} + \frac{x}{L} V_{ds} - V_t\right) dx$$

So total charge Q induced in the channel is

$$Q = \int_0^L \frac{\epsilon W}{D}\left(V_{gs} - V_{ds} + \frac{x}{L}V_{ds} - V_t\right) dx$$

$$= \frac{\epsilon W}{D}\left(V_{gs} - V_{ds} - V_t\right)L + \frac{V_{ds}}{L}\left[\frac{x^2}{2}\right]_0^L$$

$$= \frac{\epsilon W}{D}\left(V_{gs} - V_{ds} - V_t\right)L + \frac{V_{ds}}{2} \times L$$

$$\therefore Q = \frac{\epsilon WL}{D}\left(V_{gs} - V_{ds} - V_t + \frac{V_{ds}}{2}\right)$$

$$Q = \frac{\epsilon WL}{D}\left(V_{gs} - \frac{V_{ds}}{2} - V_t\right) \cdots\cdots (1)$$

Again, $Q = I_{ds} \times t$

$$t = \frac{\text{Channel Length, } L}{\text{electron velocity}}$$

$$= \frac{L}{\frac{\mu_n V_{ds}}{L}} = \frac{L^2}{\mu_n V_{ds}}$$

electron mobility

$$\mu_n = \frac{\text{electron velocity}}{\text{electric field}}$$

$$= \frac{\text{elec velocity}}{V_{ds}/L}$$

$$\therefore \boxed{\text{elec. velocity} = \frac{\mu_n V_{ds}}{L}}$$

putting the value of Q and t

putting the value of Q and t

$$I_{ds} = \frac{Q}{t} = \frac{\epsilon WL}{D}\left(V_{gs} - \frac{V_{ds}}{2} - V_t\right) \times \frac{\mu_n V_{ds}}{L^2}$$

$$= \frac{\epsilon W \mu_n}{L \cdot D}\left(V_{gs} - \frac{V_{ds}}{2} - V_t\right) V_{ds}$$

$$\boxed{\therefore I_{ds} = \frac{\epsilon \mu_n}{D} \times \frac{W}{L} \times \left[\left(V_{gs} - V_t\right)V_{ds} - \frac{V_{ds}^2}{2}\right]}$$

Resistive region Current