$$V_{TN} = \frac{|Q'_{SD(max)}|}{C_{ox}} + V_{FB} + 2|\phi_{Fp}|$$

$$V_{TN} = V_{FB} + 2|\phi_{Fp}| + \gamma\sqrt{2|\phi_{Fp}|}$$

$$V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{ox}} \quad ; \quad C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} \quad \left(F/cm^2\right)$$

$$Q'_{SD}(max) = -e N_A x_{dT} \quad ; \quad x_{dT} = \left(\frac{4\epsilon_s|\phi_{Fp}|}{eN_A}\right)^{1/2}$$

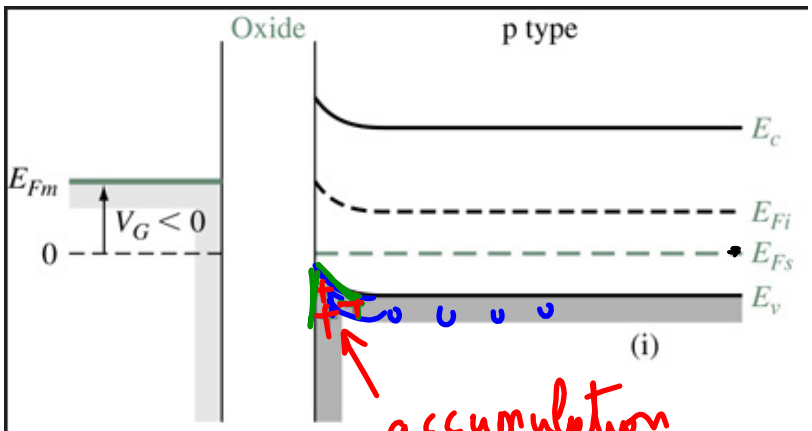
$$\phi_{Fp} = -\frac{kT}{e}\ln\left(\frac{N_A}{n_i}\right)$$

$$\frac{|Q'_{SD}(max)|}{C_{ox}} = \frac{eN_A\left(\frac{2\epsilon_s 2|\phi_{fp}|}{eN_A}\right)^{1/2}}{C_{ox}} = \underbrace{\frac{\sqrt{2e\epsilon_s N_A}\sqrt{2|\phi_{Fp}|}}{C_{ox}}}_{\gamma} = \gamma\sqrt{2|\phi_{fp}|}$$

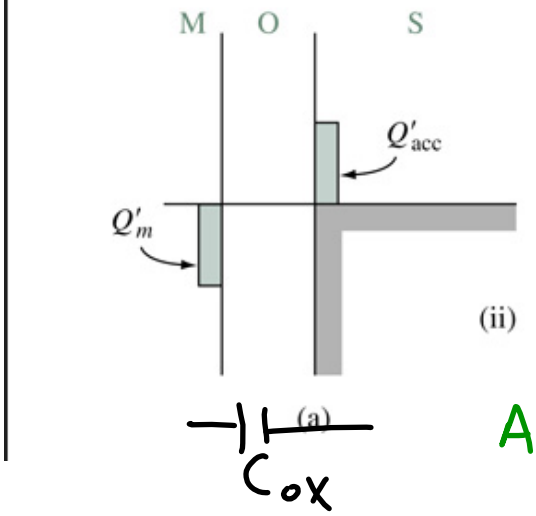
$$\gamma = \frac{\sqrt{2e\epsilon_s N_A}}{C_{ox}}$$

Ideal C – V
characteristics

$V_G < 0$



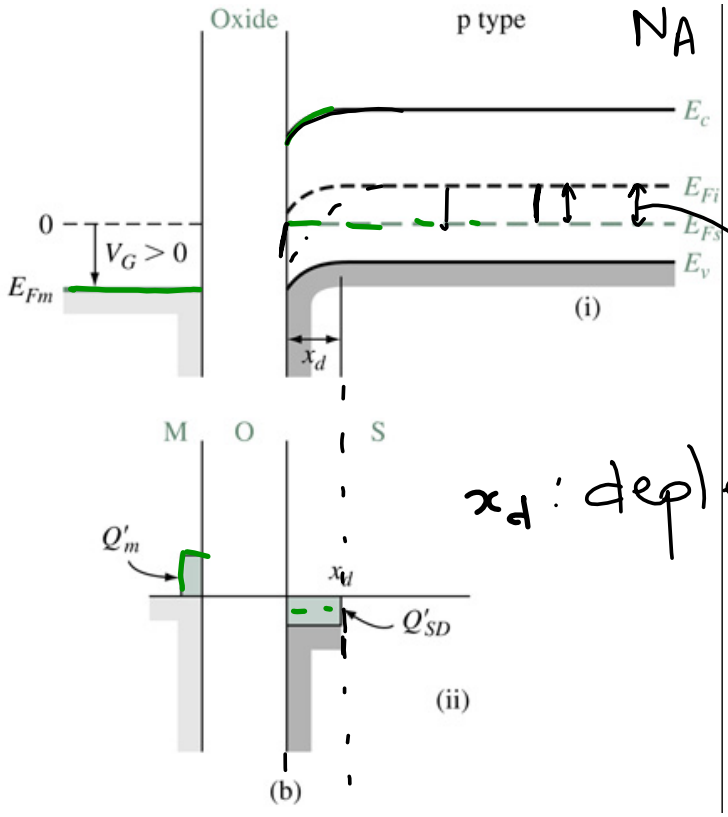
accumulation



$$C'_{(acc)} = C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$$

Accumulation

$V_G > 0$



C_{ox} C'_{SD}

$p = N_A = n_i e^{\frac{(E_{F_p} - E_{Fs})}{kT}}$

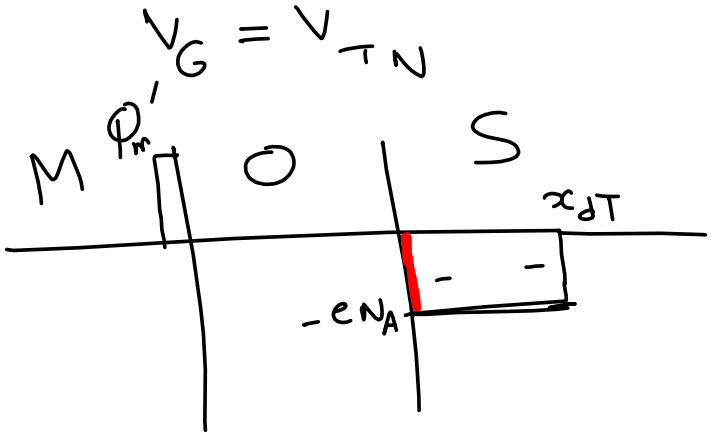
$E_{F_p} - E_{Fs} = kT \ln\left(\frac{N_A}{n_i}\right)$

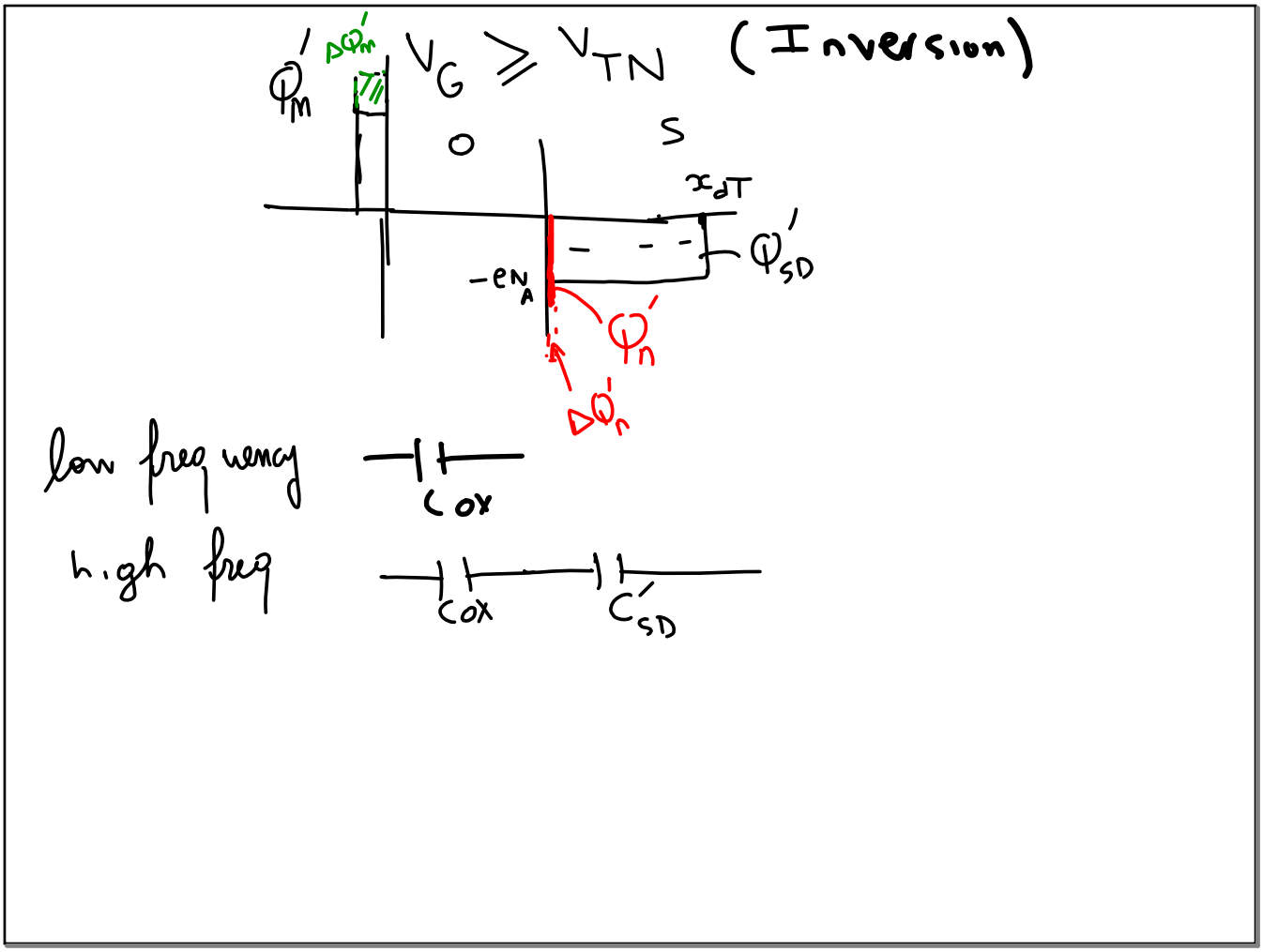
$e|\phi_{F_p}|$

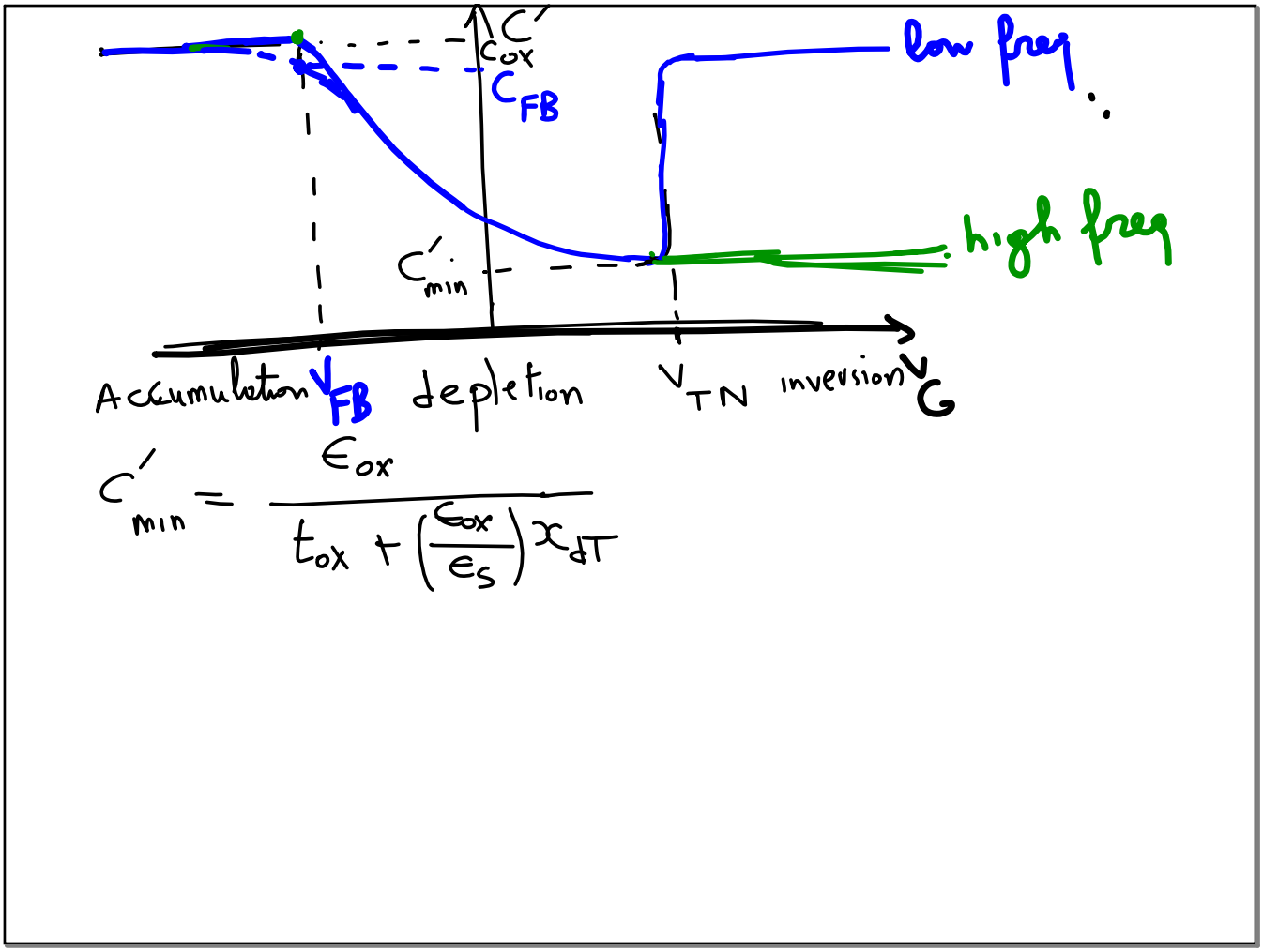
x_d : depletion width

$$\frac{1}{C'_{(depl)}} = \frac{1}{C_{ox}} + \frac{1}{C'_{SD}} \; ; \; C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} \; ; \; C'_{SD} = \frac{\epsilon_s}{x_d}$$

$$C'_{(depl)} = \frac{\epsilon_{ox}}{t_{ox} + \left(\frac{\epsilon_{ox}}{\epsilon_s}\right) x_d}$$


$V_G = V_{TN}$
Φ_m'
M
O
S
x_{dT}
$-eN_A$


$V_G \geq V_{TN}$ (Inversion)
Q'_M
$\Delta Q'_M$
O
S
x_{dT}
Q'_{SD}
$-eN_A$
Q'_n
$\Delta Q'_n$
low frequency
C_{ox}
high freq
C_{ox}
C'_{SD}

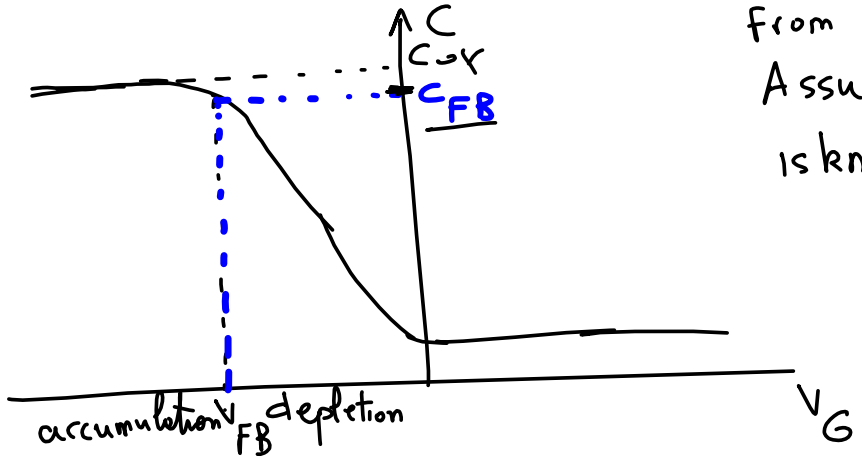


$$C'_{min} = \frac{\epsilon_{ox}}{t_{ox} + \left(\frac{\epsilon_{ox}}{\epsilon_s}\right) x_{dT}}$$

When $V_G = V_{FB}$, $x_d = L_D$ Debye Length

$$L_D = \sqrt{\frac{kT}{e}\frac{\epsilon_s}{eN_A}}$$

$$C_{FB} = \frac{\epsilon_{ox}}{t_{ox} + \left(\frac{\epsilon_{ox}}{\epsilon_s}\right)L_D}$$



From measurement:
Assume N_A is known

1) $C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} \Rightarrow t_{ox} = \frac{\epsilon_{ox}}{C_{ox}}$

b/d

2) Determine V_{FB}

$$L_D = \sqrt{\frac{kT}{e}\frac{\epsilon_s}{eN_A}}$$

$$C_{FB} = \frac{\epsilon_{ox}}{t_{ox} + \left(\frac{\epsilon_{ox}}{\epsilon_s}\right) L_D}$$

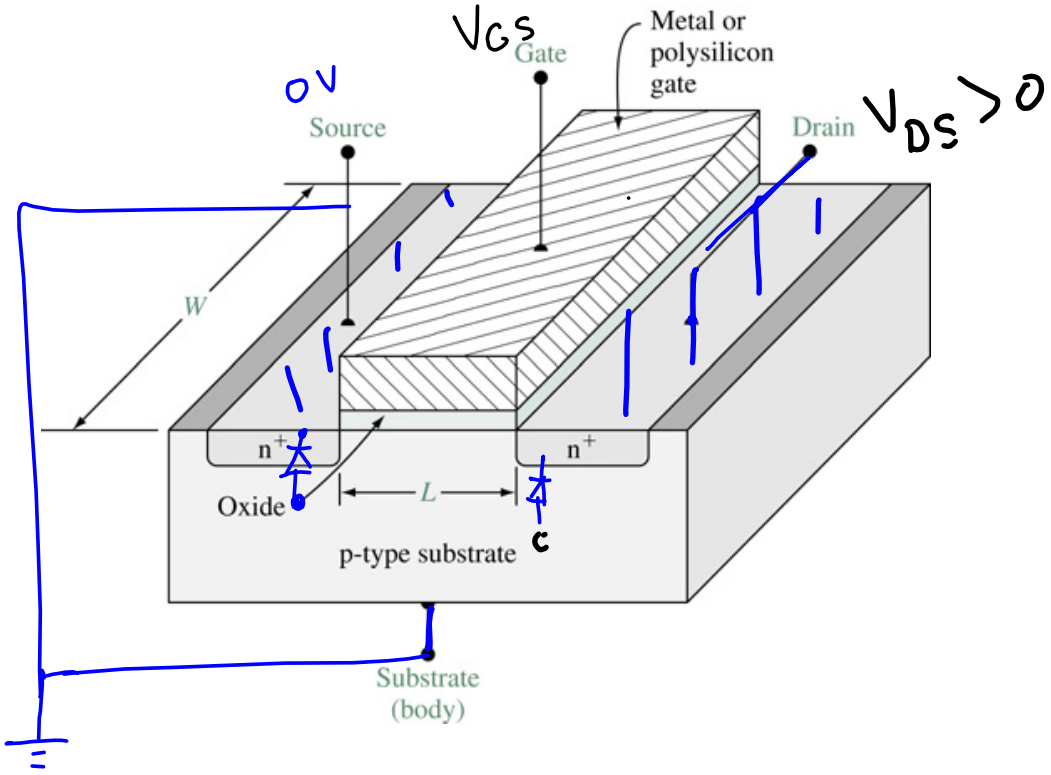
3) Extract V_{TN}

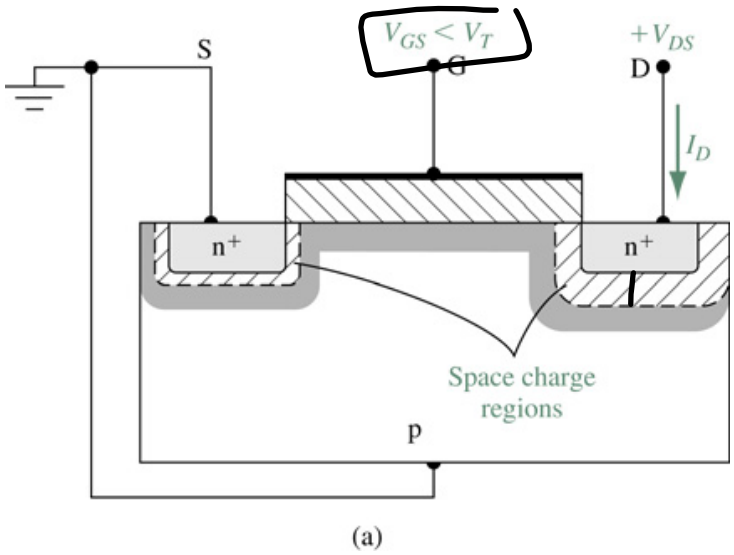
$$V_{TN} = \underline{V_{FB}} + 2|\phi_{Fp}| + \gamma\sqrt{2|\phi_{Fp}|}$$

4) Extract oxide charge Q'_{ss}

$$V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{ox}}$$

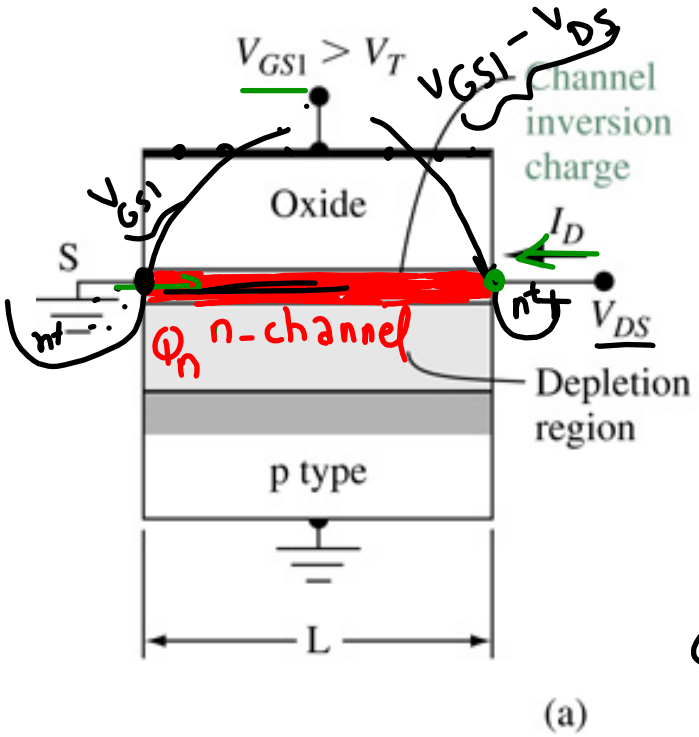
$$Q'_{ss} = C_{ox}(\phi_{ms} - V_{FB})$$

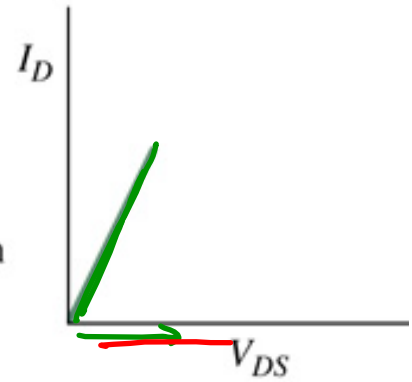

VGS
Gate
Metal or
polysilicon
gate
0V
Source
Drain
VDS > 0
W
n+
n+
Oxide
L
p-type substrate
Substrate
(body)
NMOS



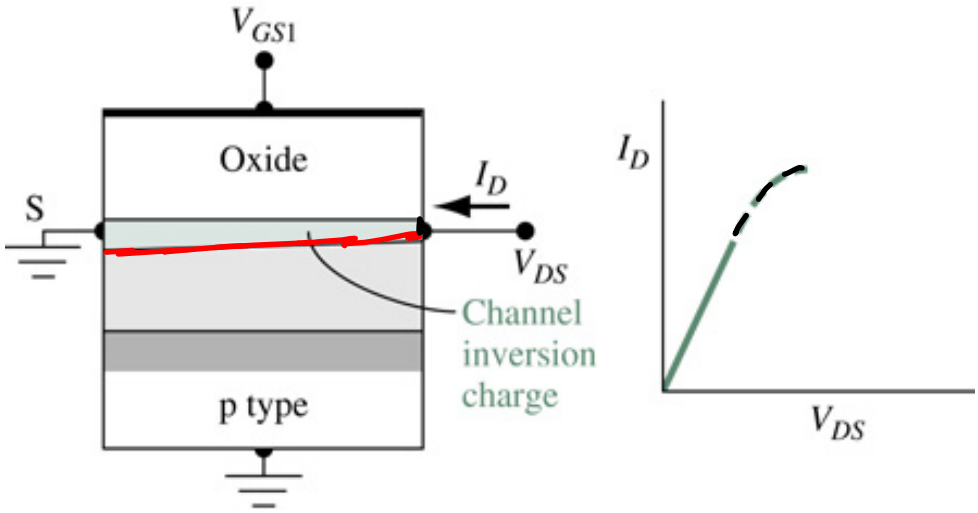
(a)

$I_D = 0$

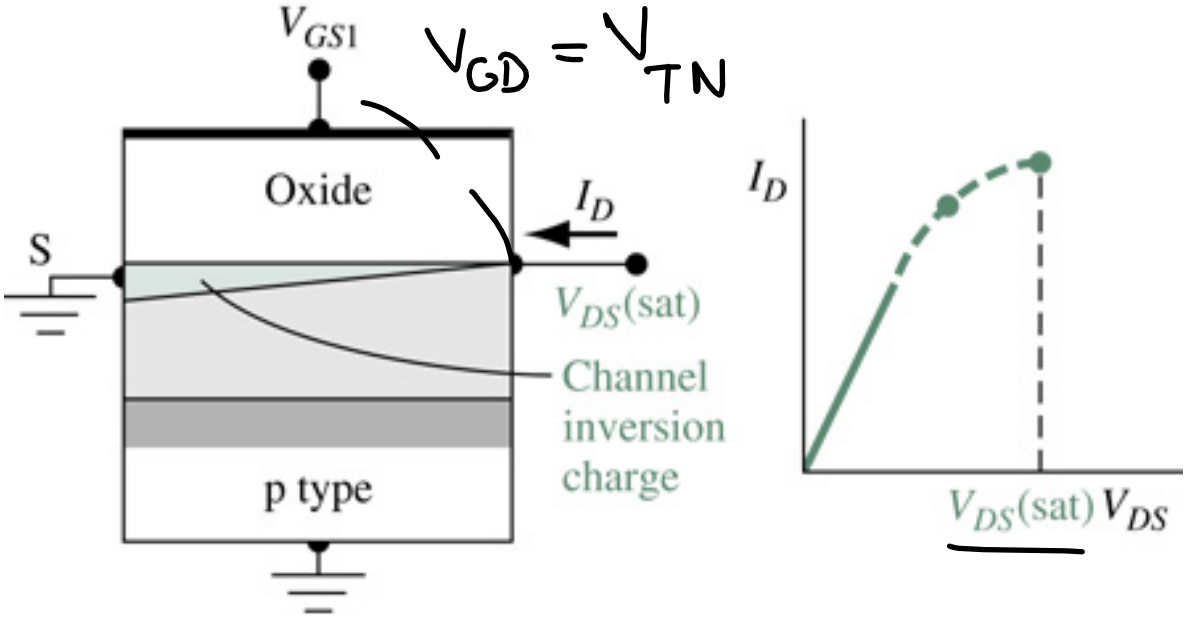




$\varphi_n = C_{ox} V$



(b)


V_{GS1}
$V_{GD} = V_{TN}$
Oxide
I_D
S
$V_{DS}(sat)$
Channel
inversion
charge
p type
I_D
$V_{DS}(sat)$ V_{DS}

(c)

Pinch off