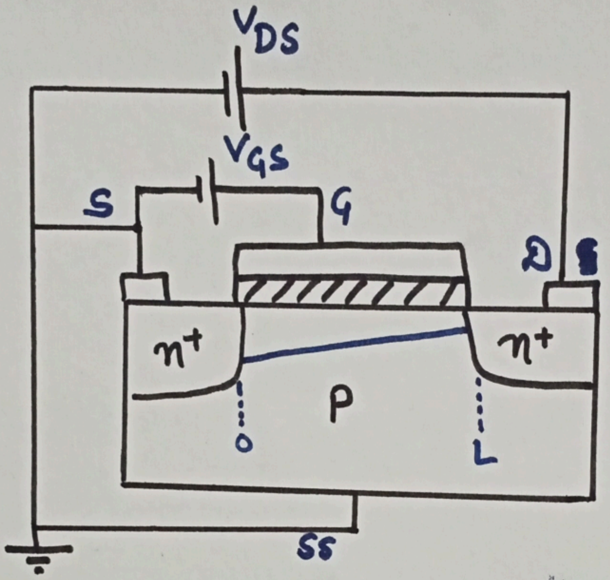
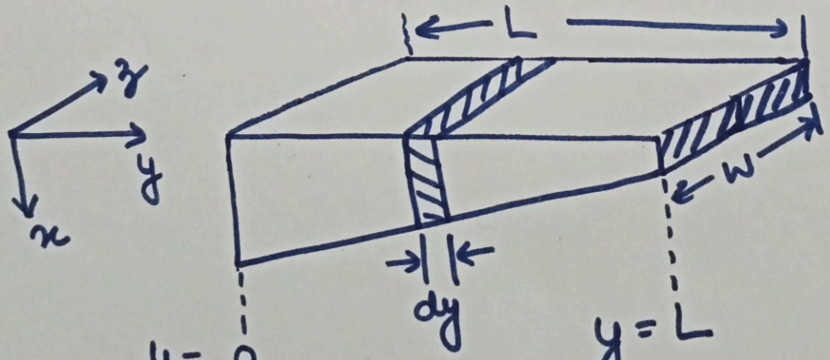
Derivation of I_D in nMOSFET





Gradual Channel Appx. model

GCA

$y = 0$
$V(y) = 0$
Source

$y = L$
$V(y) = V_{DS}$
Drain

$W \rightarrow$ Channel width
$L \rightarrow$ Channel length

To Calculate Current I_D

a) find the value of Inversion charge per unit Area. (Q_{inv})

$$Q_{inv}(y) = C_{ox}(V_{GS} - V_c(y) - V_{th})$$

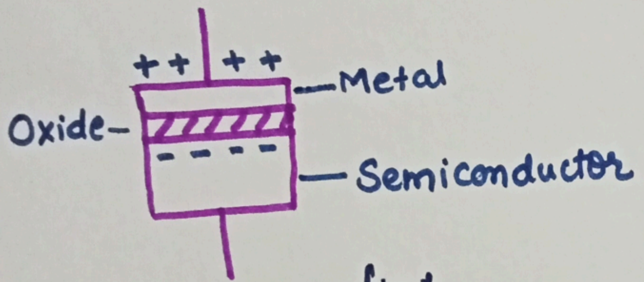


fig 1

$$\underbrace{}$$ Mos Capacitor, $C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$ [F/Area]

b) v_n, velocity of charge particles.

$$v_n = \mu_n E(y)$$

$$E(y) = \frac{dV_c(y)}{dy}$$

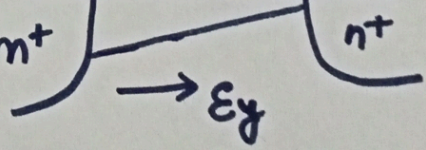


fig. 2

c) $$I_d = Q_{inv}(y)\, W\, v_n = C_{ox}(V_{GS} - V_c(y) - V_{th})\mu_n \frac{dV_c(y)}{dy}$$

$$I_{d_{lin}} = C_{ox}\left(V_{GS} - V_c(y) - V_{th}\right) W \mu_n \frac{dV_c(y)}{dy}$$

i $$\int_0^L I_d \cdot dy = C_{ox} W \mu_n \int_0^{V_{DS}} \left(V_{GS} - V_{th} - V_c(y)\right) dV_c(y)$$

ii $$I_d \cdot L = C_{ox} W \mu_n \left\{ \int_0^{V_{DS}} (V_{GS} - V_{th})\, dV_c(y) - \int_0^{V_{DS}} V(y)\, dV_c(y) \right\}$$

iii $$I_d = C_{ox} \frac{W}{L} \mu_n \left[\left| (V_{GS} - V_{th})\, V_c(y) \right|_0^{V_{DS}} - \left| \frac{V_c^2(y)}{2} \right|_0^{V_{DS}} \right]$$

iv $$I_{d_{Linear}} = C_{ox} \frac{W}{L} \mu_n \left[(V_{GS} - V_{th}) V_{DS} - \frac{V_{DS}^2}{2} \right]$$

<u>**NOTE**</u>: Equation of linear drain Current i.e. $V_{GS} \geq V_{th}$ & $V_{DS} < V_{GS} - V_{th}$

Transconductance :

$\underbrace{\mu_n C_{ox}}_{k_n'} \frac{W}{L}$ — (i)

$k_n' \frac{W}{L}$ — (ii)

$\underbrace{k_n' \frac{W}{L}}_{\text{gain factor}}$

$\frac{W}{L} \rightarrow$ Aspect Ratio

$\mu_n \rightarrow cm^2/V.sec$

$C_{ox} \rightarrow F/cm^2$

$\frac{W}{L} \rightarrow$ unit less

$$\mu_n C_{ox} \frac{W}{L} = \frac{\cancel{cm^2}}{V.Sec} \cdot \frac{F}{\cancel{cm^2}}.$$

$$= \frac{\cancel{cm^2}}{V.S} \cdot \frac{Q}{V.\cancel{cm^2}}$$

$$= \frac{I}{V^2} \quad \left(A/V^2\right)$$

"Unit of transconductance"

$$K_n = k_n' \frac{W}{L}$$

i $$I_{d_{lin}} = \underbrace{\mu_n C_{ox} \frac{W}{L}}_{k_n} \left[(V_{GS} - V_{th}) V_{DS} - \frac{V_{DS}^2}{2} \right]$$

Example :

(ii) Let $K_n = 40 \ mA/V^2$

$V_{GS} = 3V$, $V_{th} = 1V$

S.No.	V_{DS}	I_d
1.	0	
2.	1	
3.	2	
4.	3	
5.	4	
6.	5	
7.	6	

Equation of $I_{D_{sat}}$

(i) In $I_{d_{lin}} = \frac{W}{L}\mu_n C_{ox}\left[(V_{GS}-V_{th})V_{ds} - \frac{V_{ds}^2}{2}\right]$

(ii) put $V_{ds} = V_{ds_{sat}} = V_{GS} - V_{th}$, $I_{d_{sat}}$

(iii) $$I_{d_{sat}} = \frac{W}{2L}\mu_n C_{ox}\left[(V_{GS}-V_{th})^2 - \frac{(V_{GS}-V_{th})^2}{2}\right]$$

$$= \frac{W}{2L}\mu_n C_{ox}(V_{GS}-V_{th})^2$$

Note: It is valid for $V_{GS} \geq V_{th}$ +

$V_{ds} > \underbrace{V_{GS} - V_{th}}_{V_{ds_{sat}}}$