EI-27003: Electronics Devices and Circuits
Lecture - 10

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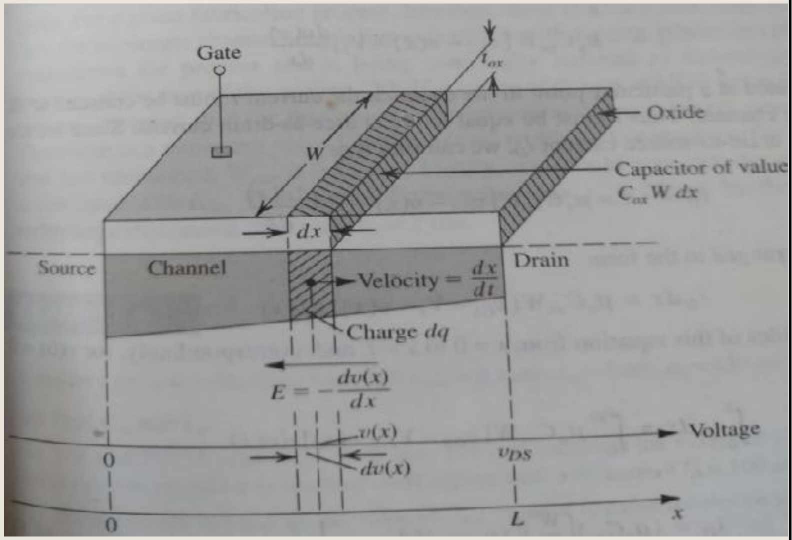
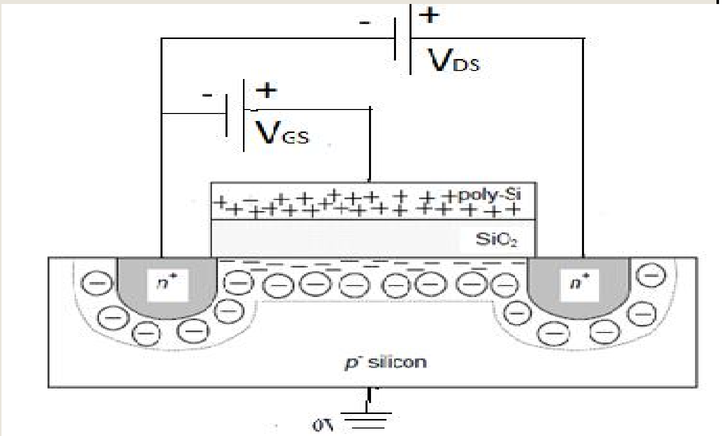
LECTURE - 10

Year: 2020-21

Derivation of Drain Current I_D



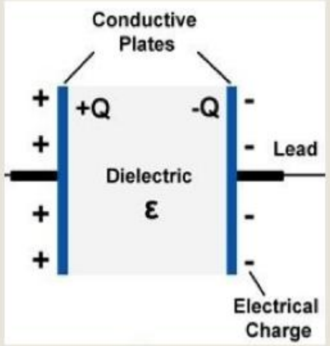
- Let us assume that V_{GS} is applied between Gate and Source with $V_{GS}>V_t$ to induce channel.
- Also assume that VDS is applied between drain and source.
- Let us consider triode region in which $V_{DS} < (V_{GS}-V_t)$
- In this case channel will have tapered shape as shown in cross sectional view.



- Now gate is connected to +ve plate of Battery have +ve charges on it.
- Channel formed is of electrons (-ve), have –ve charges on it.
- In between these +ve and –ve layers, there is SiO_2 layer which is dielectric.

Derivation……….

- Hence the gate and channel region forms a parallel plate capacitor. If capacitance per unit gate area is denoted as C_{ox} and thickness of oxide layer is t_{ox}, then



$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} \quad \text{------ (1)}$$

- Where: ε_{ox} is the permittivity of silicon dioxide

$$\varepsilon_{ox} = 3.9 \times \varepsilon_o = 3.9 \times 8.8854\times10^{-12} = 3.45\times10^{-11} \text{F/m}$$

- Now consider cross sectional view and consider infinitesimal strip of the gate at distance x from source.
- The capacitance of this strip is = $C_{ox}.w.dx$ ------(2)
- To find the charge stored on this strip of gate capacitance, we multiply the capacitance by effective voltage between gate and channel at point x.
- This effective voltage at point x will be = $[V_{GS} - V_t - V(x)]$ ------(3)
- Hence electron charge dq in infinitesimal portion of channel at point x is

$$dq = - C_{ox}.w.dx\,[V_{GS} - V_t - V(x)] \quad \text{------(4)}$$

-ve sign is negative charge.

Derivation……….

- The voltage VDS produces electric field along the channel in the negative x direction. At point x this field can be expressed as;

$$E(x) = -\frac{dV(x)}{dx} \quad \text{-------(5)}$$

- The electric field E(x) causes the electron charge dq to drift towards the drain with velocity dx/dt

$$\frac{dx}{dt} = -\mu_n E(x) = \mu_n \frac{dV(x)}{dx} \quad \text{-------(6)}$$

- Where μ_n is the mobility of electrons in the channel.
- Thus the resulting drift current 'i' is obtained as:

$$i = \frac{dq}{dt} \text{ or } \frac{dq}{dx}\frac{dx}{dt} \quad \text{---------(7)}$$

- Substitute $\frac{dq}{dx}$ from eq.(4) and $\frac{dx}{dt}$ from eq.(6), then

$$i = -\mu_n C_{ox}.w.\ [V_{GS} - V_t - V(x)] \frac{dV(x)}{dx} \quad \text{--------(8)}$$

Derivation……….

- Although evaluated at a particular point in the channel, the drift current (electron current) 'i' must be constant at all points along the channel.
- As we are interested in drain current (conventional current) I_D:

$$I_D = -i = \mu_n C_{ox}.w.\ [V_{GS} - V_t - V(x)]\frac{dV(x)}{dx} \quad \text{-------(9)}$$

➢ Rearrange this equation:

$$I_D\, dx = \mu_n C_{ox}.w.\ [V_{GS} - V_t - V(x)]\, dV(x) \quad \text{--------(10)}$$

➢ Integrating both sides of this equation from x=0 to x=L correspondingly for V(0)=0 to V(L)=V_{DS}

$$\int_0^L I_D\, dx = \int_0^{V_{DS}} \mu_n C_{ox}.w.\ [V_{GS} - V_t - V(x)]\, dV(x) \quad \text{-------(11)}$$

Solving this integration gives:

$$\mathbf{I_D = \mu_n C_{ox}(W/L)\ [(V_{GS} - V_t)V_{DS} - \tfrac{1}{2}V^2_{DS}]}$$ for $V_{DS} < (V_{GS} - V_t)$ triode region

------(12)

Drain Current I_D for Saturation Region

- As we know if V_{DS} becomes equals to $(V_{GS}-V_t)$, the channel gets pinched-off and NMOS is just on verge of Saturation.
- So equation (12) becomes:

$$I_D = \mu_n C_{ox}(W/L)\left[(VGS - Vt)V_{DS} - \frac{1}{2}V^2{}_{DS}\right] \text{-----}(12)$$

Substitute $V_{DS} = (V_{GS}-V_t)$

$$I_D = \mu_n C_{ox}(W/L)\left[(VGS - Vt)(VGS - Vt) - \frac{1}{2}(VDS - Vt)2\right]$$

$$\mathbf{I_D = \frac{1}{2}\mu_n C_{ox}(W/L)(VDS - Vt)2} \quad \text{for } V_{DS} \geq (V_{GS}-V_t) \text{ Saturation Region}$$

- Here $\mu_n C_{ox}$ is constant and is called as Process Trans-conductance Parameter.
- It is denoted by K_n and has dimensions of A/V^2

$$I_D = K_n(W/L)\left[(VGS - Vt)V_{DS} - \frac{1}{2}V^2{}_{DS}\right] \quad \text{Triode region}$$

$$I_D = \frac{1}{2}K_n(W/L)(VDS - Vt)^2 \quad \text{Saturation region}$$

Its time for Quiz

https://forms.gle/TWepKdJg1hMjJZNV6