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Module - 6

Field Effect Transistor

* **Overview** :-

① Metal - Semiconductor Junction
↓
② MOSCAP [fundamental of MOSFET]
↓
③ MOSFET

↙ ↓ ↘ ↘

Construction   Types   Operation   Characteristics

Types:
↙ ↘

Enhancement mode: n-channel, p-channel

Depletion mode: n-channel, p-channel

* **Metal - Semiconductor Junction**:

↳ boundary between a metal and a semiconductor material

⇓

2 Types

↙ ↘

Ohmic contact
↓
- allows flow of current in both directions
- Non-rectifying

Schottky diode
↓
- allows flow of current in one direction
- Rectifying

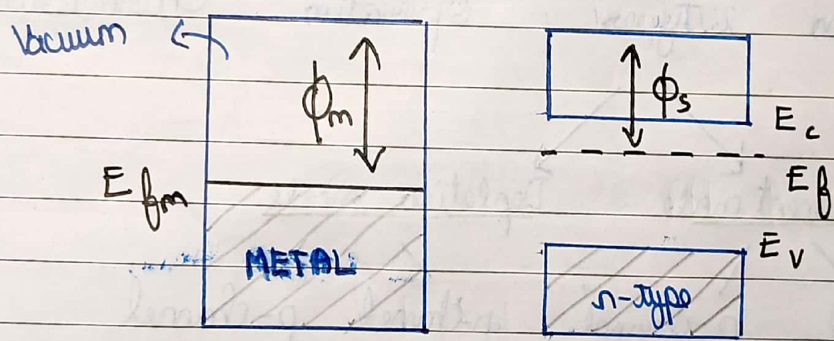
- $\phi_m < \phi_s \rightarrow$ n-type
  $\phi_m > \phi_s \rightarrow$ p-type

- $\phi_m > \phi_s \rightarrow$ n-type
  $\phi_m < \phi_s \rightarrow$ p-type

Here, $\phi_m \rightarrow$ work function of metal
$\phi_s \rightarrow$ work function of semiconductor.

- <u>Work Function</u> (ϕ) $\rightarrow$ Energy required by electron to move from the fermi-level to the vacuum level, i.e, top of conduction band.

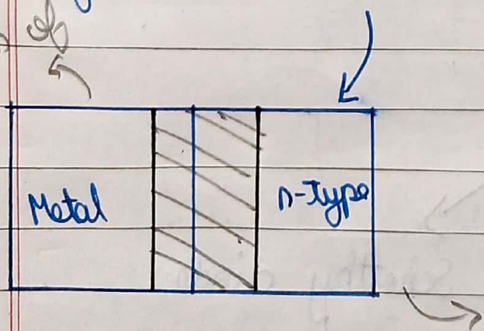
$\rightarrow$ <u>Before contact</u> of a metal & semiconductor, the Energy band diagram is, (Schottky contact)



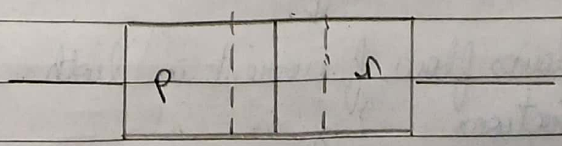
$\rightarrow$ <u>Upon contact</u> of MS junction, electrons will keep moving between the metal and the semiconductor until their respective ~~for~~ fermi level is alligned, causing the formation of a depletion region.

$\hookrightarrow$ done to attain thermal equilibrium condition

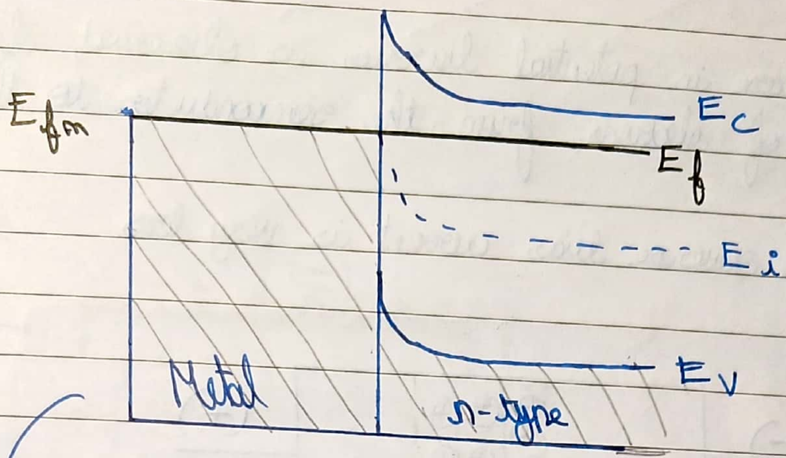
formation of depletion region



In PN diode, (unbiased)



→ After contact, the required Energy band diagram is,



E^- move from semiconductor to metal

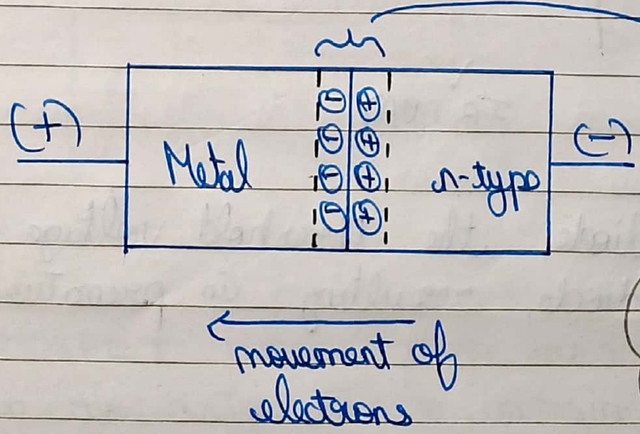
↳ Here, a large potential barrier height is formed, given by the energy difference b/w band edge with majority carriers and fermi energy of metal.

• Under forward bias,

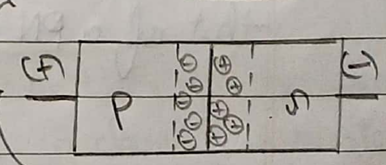
↳ reduction in size of potential barrier occurs, resulting in easier transfer of electrons from semiconductor to the metal.

↳ With increasing forward voltage (V_a), more current will be produced.

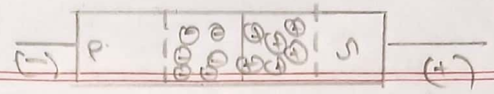
The depletion region can be represented as,



In PN



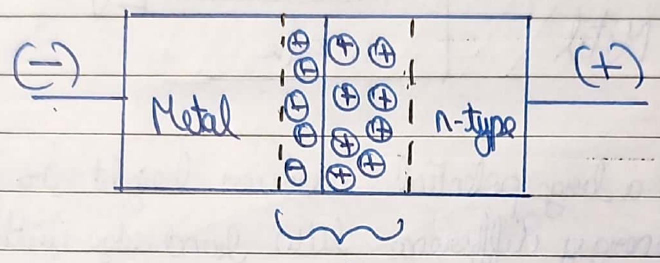
In pn diode,



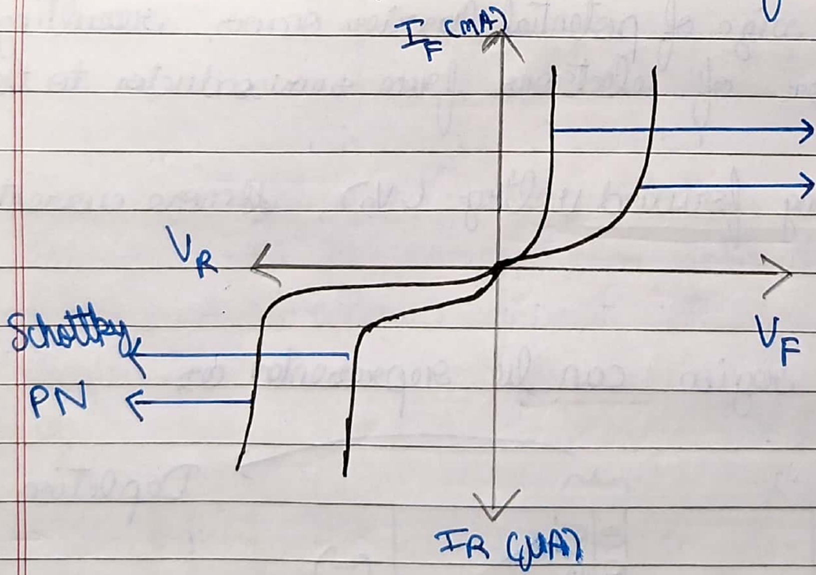
- Under reverse bias,

↳ an increase in potential barrier is observed, blocking the diffusion of electrons from the semiconductor to the metal.

↳ Here, the reverse bias current is very less.



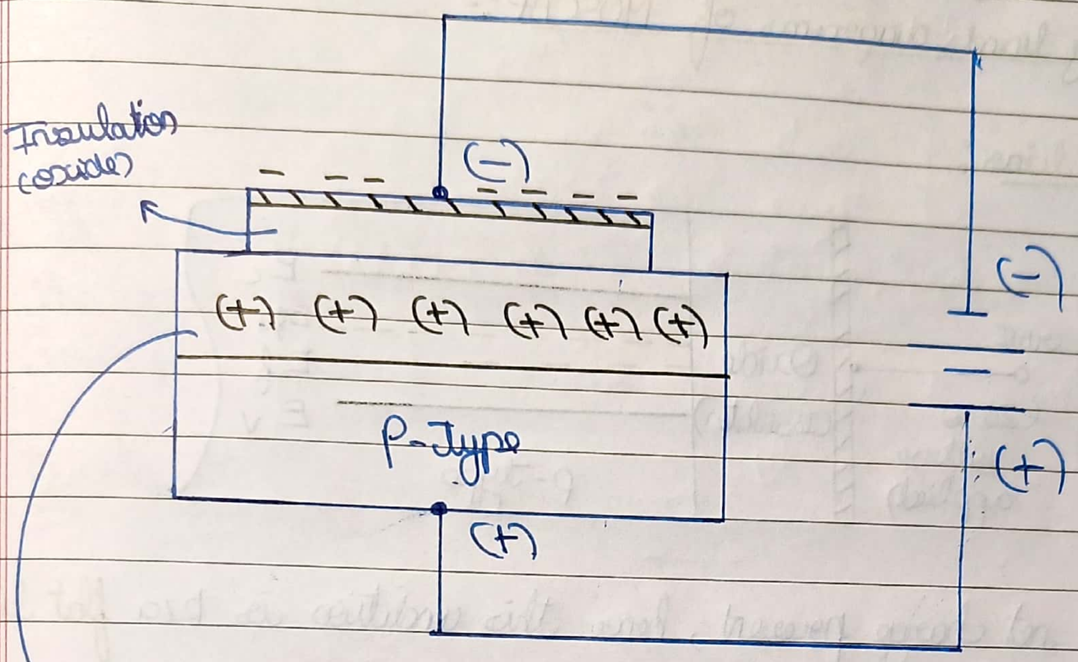
- The i/p and o/p characteristics of PN Vs Schottky is,



In a MS diode, the threshold voltage is less than that of a PN diode, resulting in premature current flow.

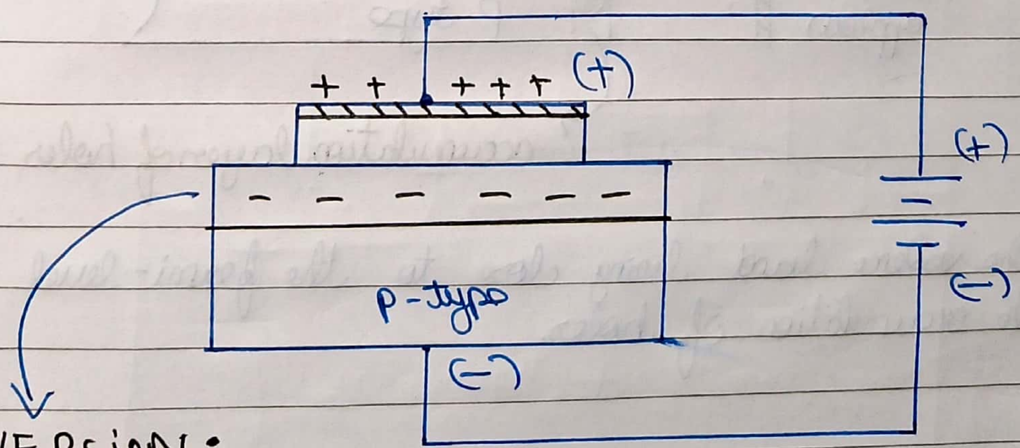
* **MOSCAP** (Metal Oxide Semiconductor Capacitor):

• Under forward bias,



Accumulation layer of Holes:
Here, the p-type semiconductor has holes as the majority charge carrier and under forward bias, the positive charge repels the holes, making them accumulate at the top layer of the substrate.

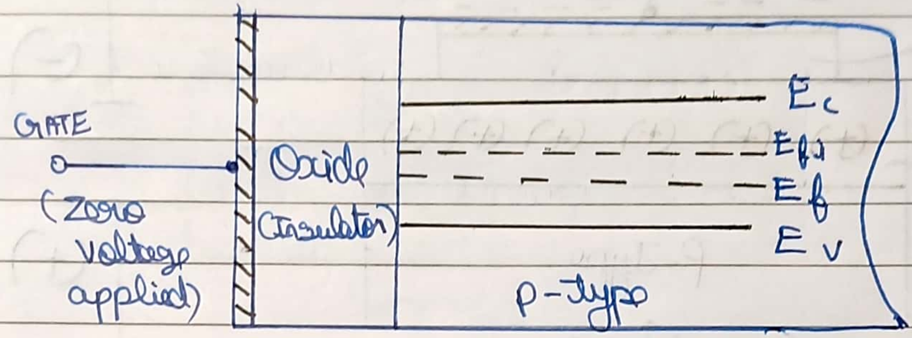
• Under reverse bias,



INVERSION:
Occurs in MOSFET when electrons are accum'd in p-type and the holes in the n-type. Due to inversion, a channel is created b/w the MS junction and a depletion region is created.

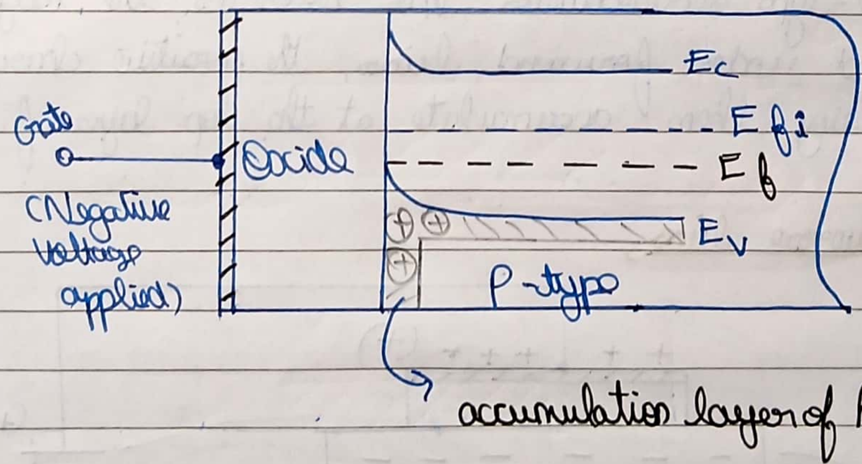
• Energy band diagrams of MOSCAP:-

(1) Zero-bias:



→ No net charge present, hence this condition is k/a flat band.

(2) Forward-bias:



→ The valence band being close to the fermi-level indicates the accumulation of holes.

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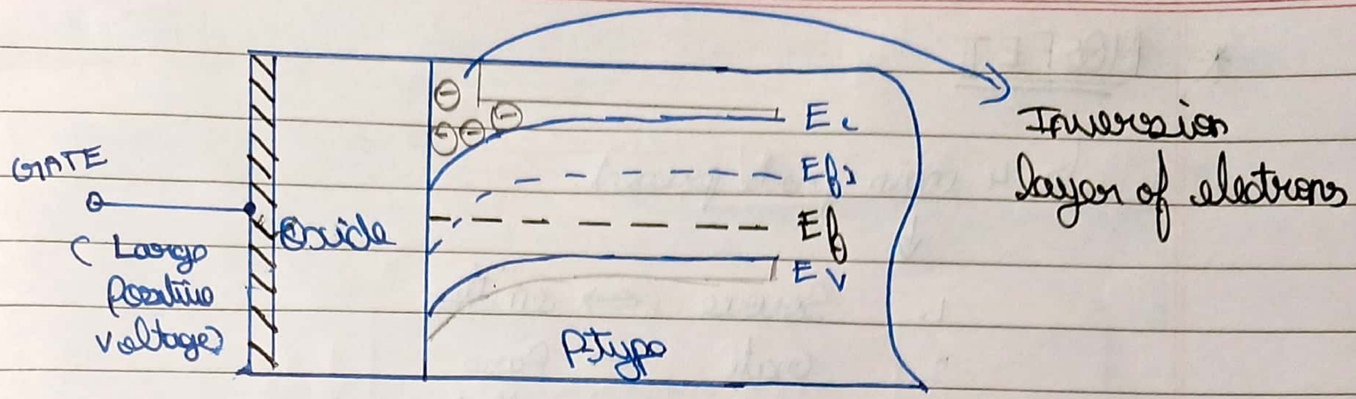


→ The conduction band and intrinsic fermi-levels move closer to the fermi-level and due to sufficient positive voltage, inversion layer is achieved.

• <u>Depletion Layer thickness:</u>

↳ The width of channel formed, x_d

$$\boxed{x_d = \left(\frac{2\varepsilon_s \phi_s}{e N_a}\right)^{1/2}}$$

$$\boxed{\phi_{fp} = V_t \ln\left(\frac{N_a}{n_i}\right)}$$

$$\boxed{x_{dT} = \left(\frac{4\varepsilon_s \phi_{fp}}{e N_a}\right)^{1/2}}$$

at $\phi_s = 2\phi_{fp}$

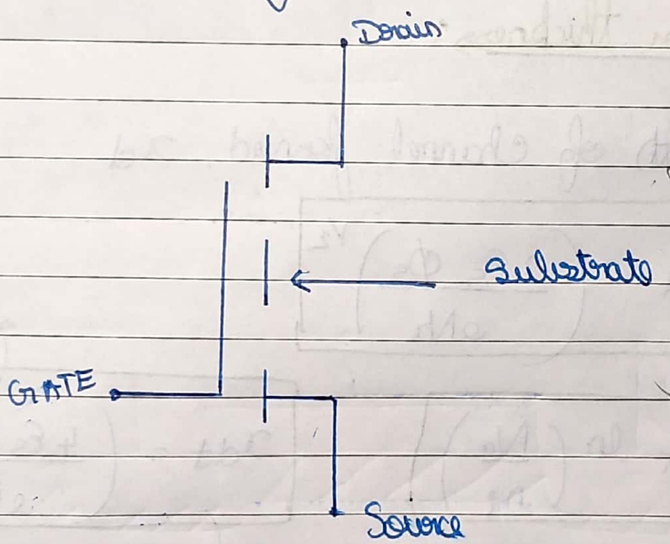
Here, ϕ_s → region b/w new E_{fi} and old E_{fi}.

* MOSFET

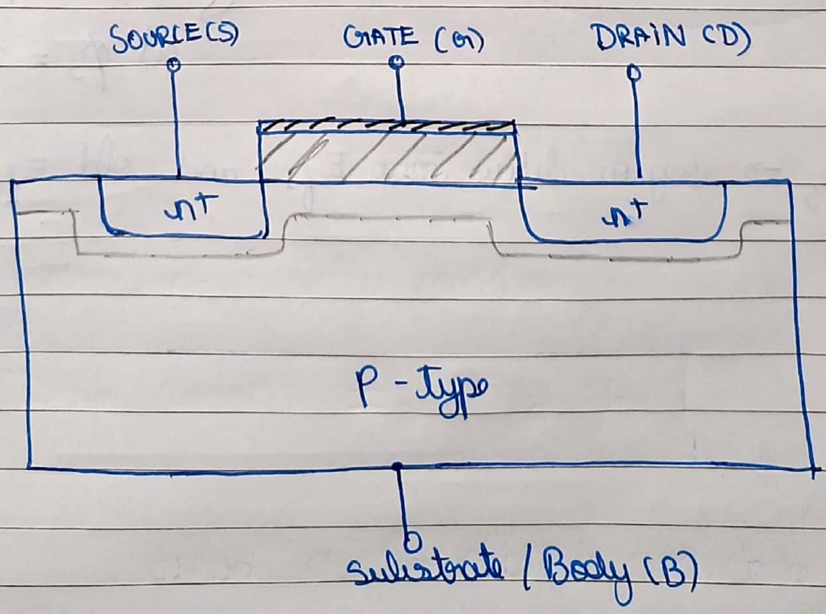
↳ 4 main parts present.
↓

1. Source ↔ emitter
2. Gate ↔ Base
3. Drain ↔ collector
4. Substrate

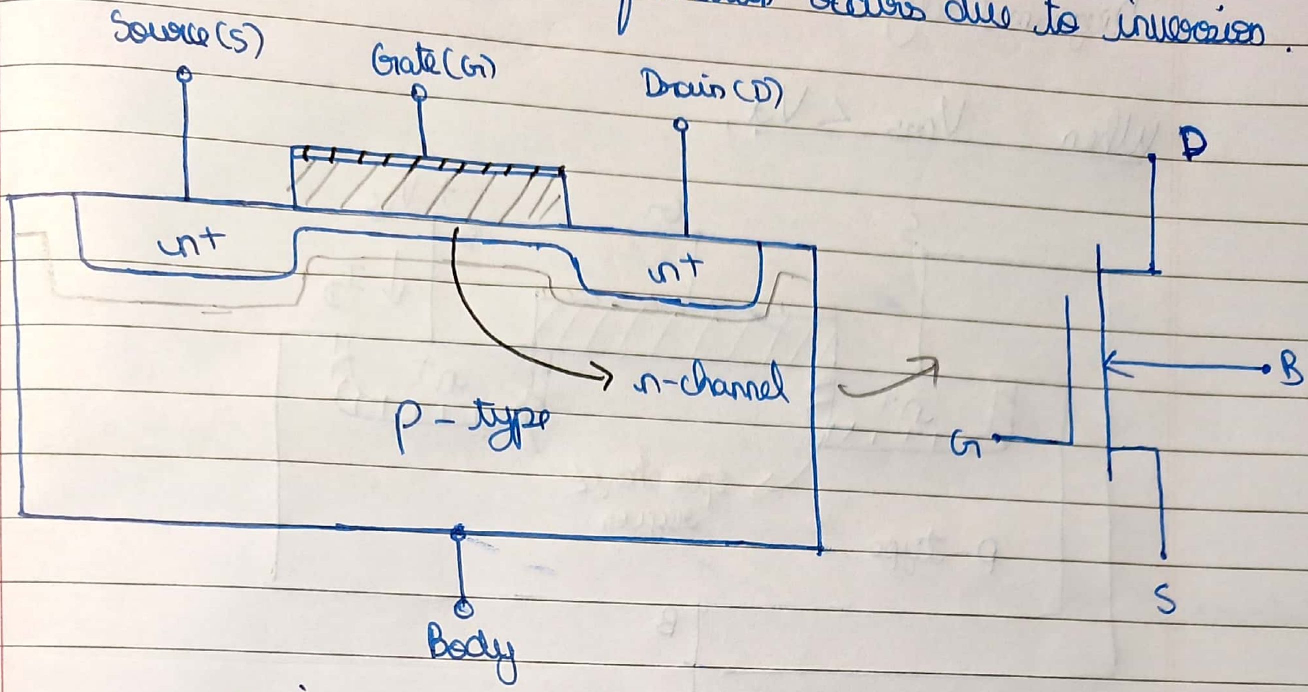
• In enhancement mode, no channel is formed
⇓



GAPS present due to no channel formation



- In depletion mode, channel formation occurs due to inversion.



→ Inversion ~~layer~~ region is formed at a particular voltage, i.e. threshold voltage (V_t) and for channel formation, $V_{GS} \geq V_t$. Here, V_{GS} → Gate-source voltage.

∴ For Channel formation → $V_{GS} \geq V_t$

n-channel formation → $V_{GS} > V_t$
p-channel formation → $V_{GS} < V_t$

- Current-Voltage Characteristics:

THEORY

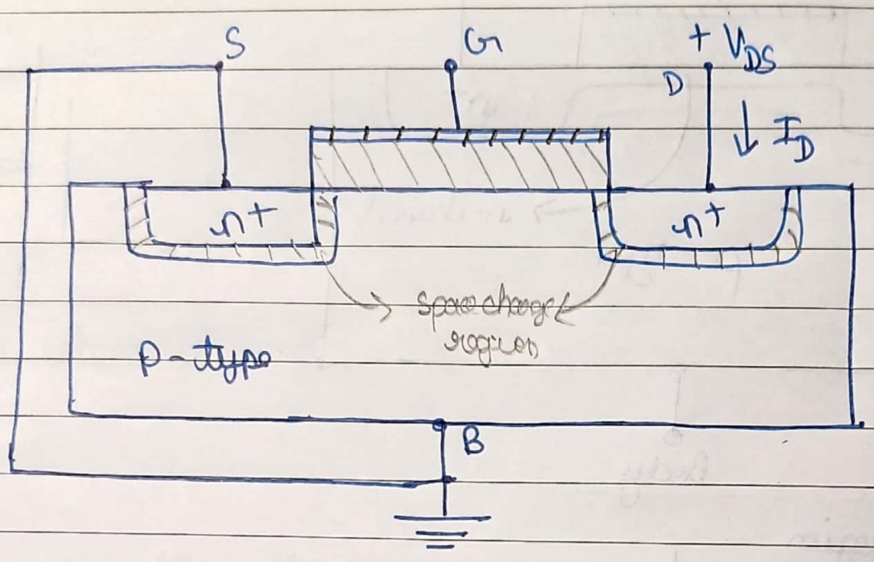
→ The source and the substrate are connected to the ground and are hence, negative.

→ With an applied voltage $V_{GS} > V_t$, an inversion layer is formed and the electrons in the inversion layer are pushed through the channel due to the negative charges of the source and substrate.

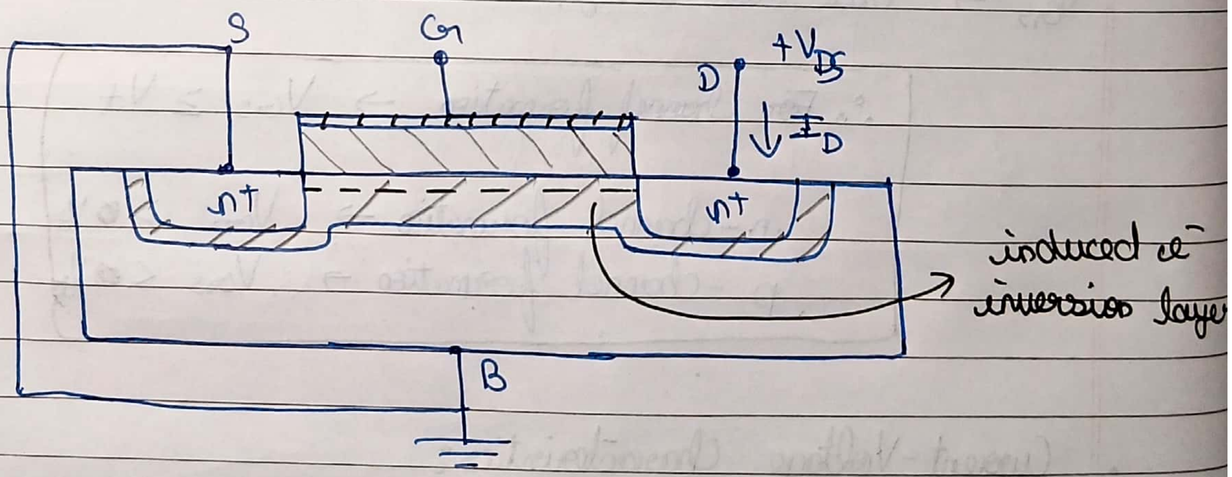
→ To remove the electrons, V_{DS} is kept positive, making the Drain positively charged.

Diagramatically,

- When $V_{GS} < V_t$,



- When $V_{GS} > V_t$,



- Now, under non-saturation condition,

$$\boxed{\text{Drain current, } I_D = g_d V_{DS}}$$

where, $g_d \rightarrow$ channel conductance

$$\boxed{g_d = \frac{W}{L} \mu_n |Q_n'|}$$

where $W \rightarrow$ width

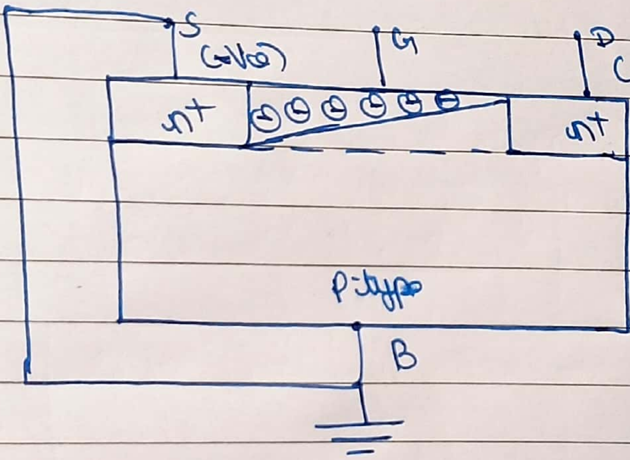
$L \rightarrow$ length

$\mu_n \rightarrow$ mobility of e^- in inversion layer

$Q_n' \rightarrow$ charge per unit area at channel

- **Saturation region:**

  ↳ obtained when V_{DS} keeps increasing, keeping I_D constant.



$$V_{DS(sat.)} = V_{GS} - V_T$$

Under saturation, the channel near drain region keeps decreasing and at one point, the channel gets small enough to completely stop the e^- flow.

↳ at this point, the maximum current is observed, the point is also k/a Threshold inversion point.

- **Output characteristics** (Drain, observed at saturation)