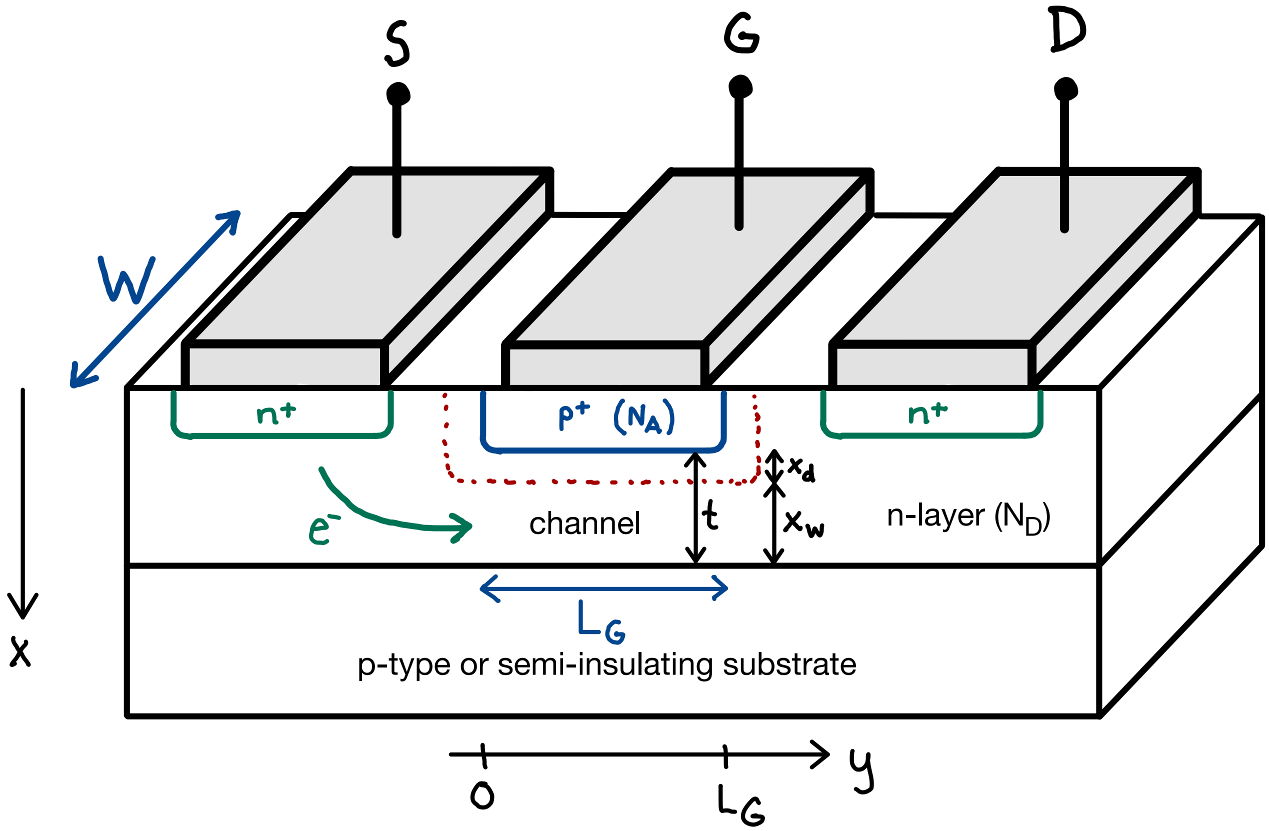
Devices That Employ p-n and/or Schottky Diodes

- Photodiode
- Junction Field Effect Transistor (JFET)
- Metal-Semiconductor FET (MESFET)
- High Electron Mobility Transistor (HEMT) / Heterojunction FET (HFET)
- Bipolar Junction Transistor (BJT) / Heterojunction Bipolar Transistor (HBT)

JFET (Junction FET)

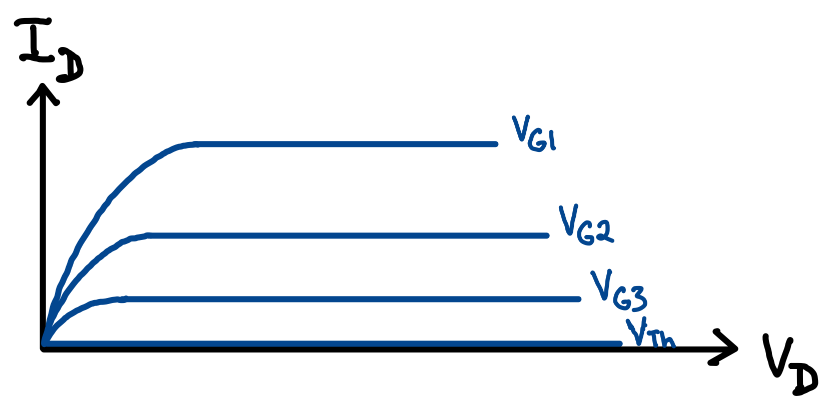


Under bias:

$V_S = 0V$

$V_G \leq 0\,V$

$V_D \geq 0\,V$



Principles of Operation

- Electrons flow from source (V_S = 0V) to drain (V_D > 0V) through the channel

- Applying a negative bias to the gate increases the thickness x_d of the depletion region, thereby reducing the thickness x_w of the channel and decreasing its conductance (i.e., increasing R_{ch})

- If V_G is sufficiently negative such that $x_w = 0$, no current will flow through device

$$x_w = t - x_d$$

$$x_d = \left[\frac{2\epsilon_s}{qN_D}\left(V_{bi} - V_G\right)\right]^{1/2} \quad \text{(1-side p-n junction, } N_A \gg N_D\text{)}$$

$$V_{bi} = \frac{kT}{q} \ln\left[\frac{N_A \cdot N_D}{n_i^2}\right]$$

When $V_G = V_{Th}$ (threshold voltage), $x_w = 0$, so $x_d = t$

$$\boxed{V_{Th} = V_{bi} - \frac{qN_D t^2}{2\epsilon_s}}$$

- At small drain voltages, current increases approximately linearly. As drain voltage increases, drain side of channel becomes narrower and current increases at a lower rate and eventually saturates (more details below).

For small V_D:

$$R_{ch} = \frac{\rho L_G}{x_w \cdot W} \quad \rightarrow \quad \rho = (q \mu_n N_D)^{-1}$$

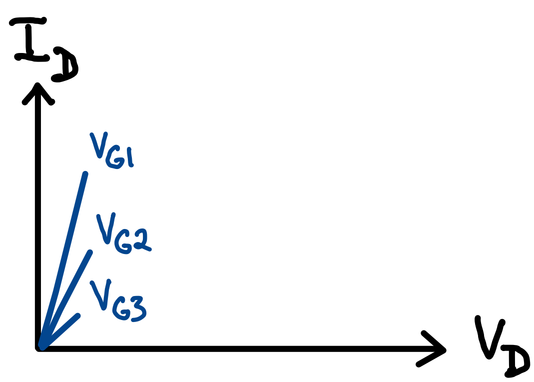
$$I_D = \frac{V_D}{R_{ch}} = \left(\frac{W}{L_G}\right) \cdot q \mu_n N_D x_w \cdot V_D$$

↑ Derived above

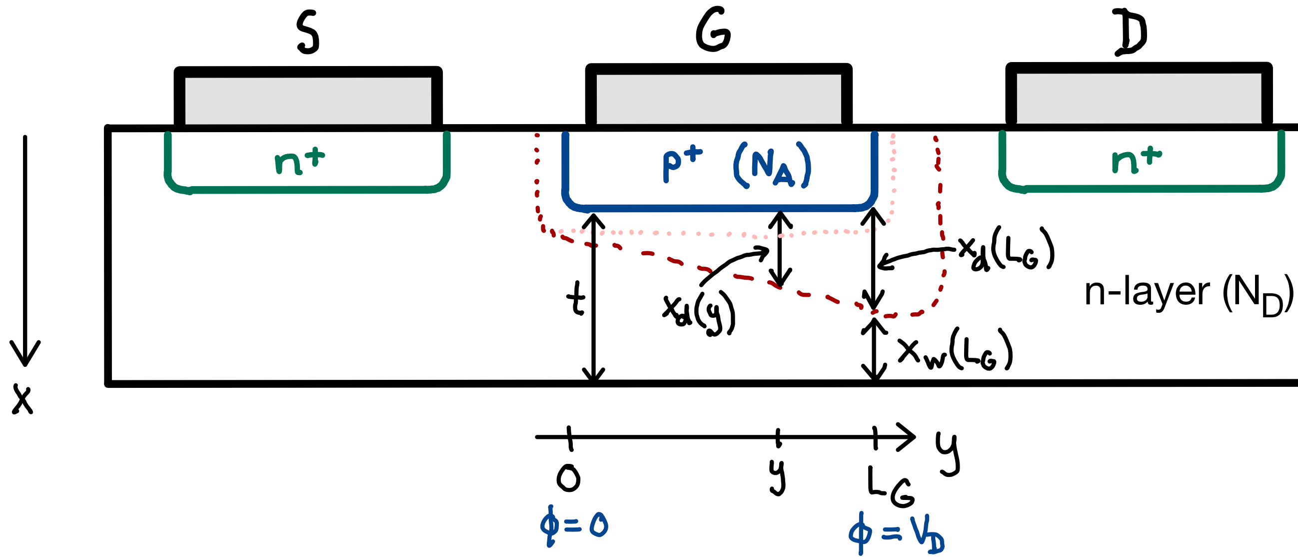
Plugging in expression for x_w:

$$\boxed{I_D = G_0 \left\{ 1 - \left[\frac{2\epsilon_s}{q N_D t^2} (V_{bi} - V_G) \right]^{1/2} \right\} V_D}$$

where $G_0 = \frac{W}{L_G} q \mu_n N_D t$



For larger V_D:

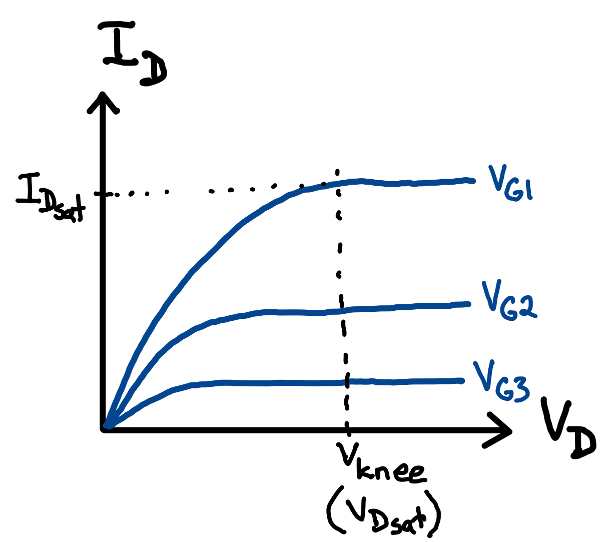


- Assume L_G long → apply gradual channel approximation (i.e., $\mathcal{E}_x$ and $\mathcal{E}_y$ are independent)

- In the channel under the gate, the potential ϕ varies as a function of y:
  - $\phi(0) = 0$ and $\phi(L_G) = V_D$

- Accordingly, $x_d(y)$ increases with increasing y
  - $x_d(y) = \left\{ \frac{2\epsilon_s}{qN_D} \left[V_{bi} - V_G - \phi(y) \right] \right\}^{1/2}$

- As V_D gets larger:
  - x_w decreases on drain side of channel
  - R_{ch} increases, so I_D is no longer linear
  - When $x_d(L_G) \rightarrow t$, $R_{ch} \rightarrow \infty$ and current saturates



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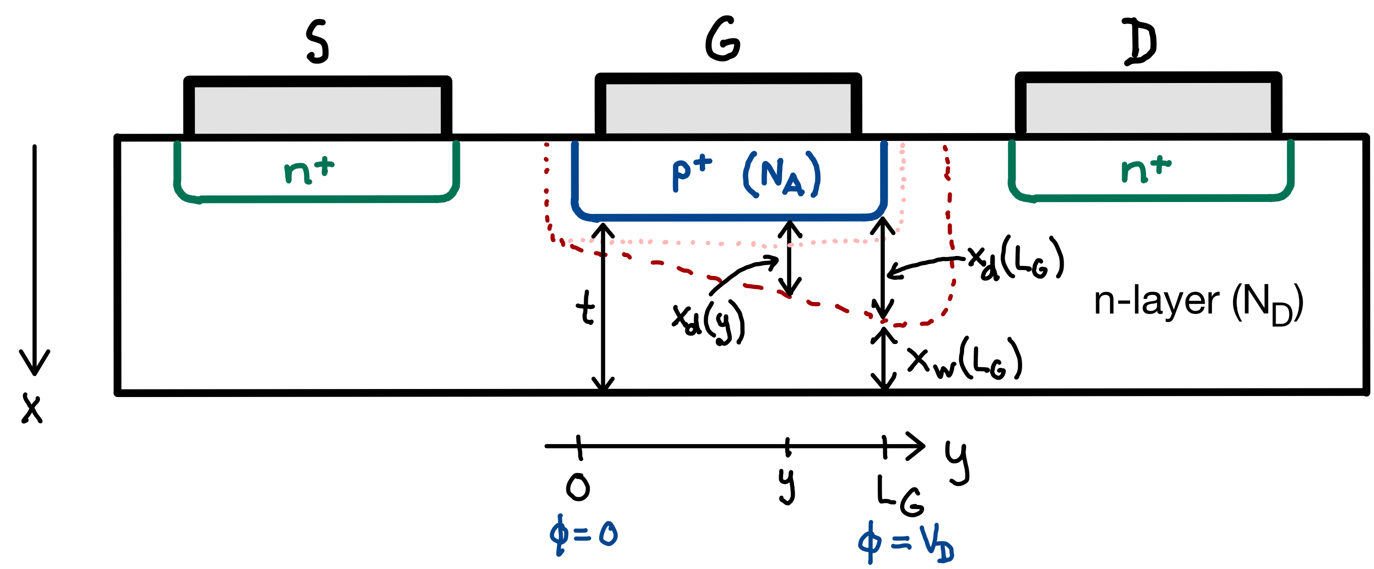
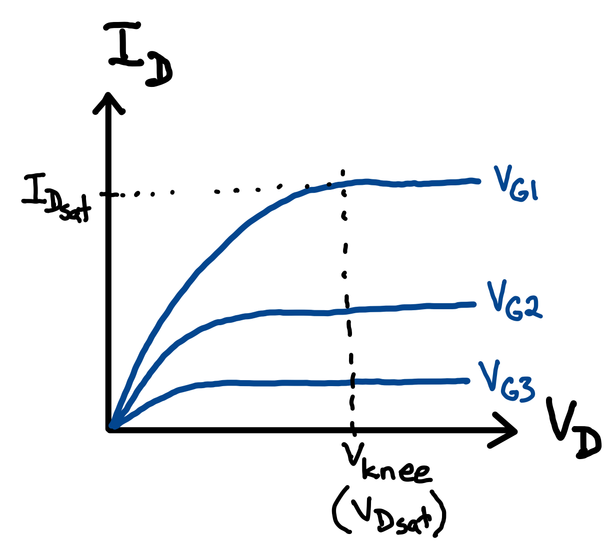


- $\phi(L_G) = V_{knee}$ when $x_d(L_G) \approx t$:

- $t = \left\{ \frac{2\epsilon_s}{qN_D} \left[V_{bi} - V_G - V_{knee} \right] \right\}^{1/2}$

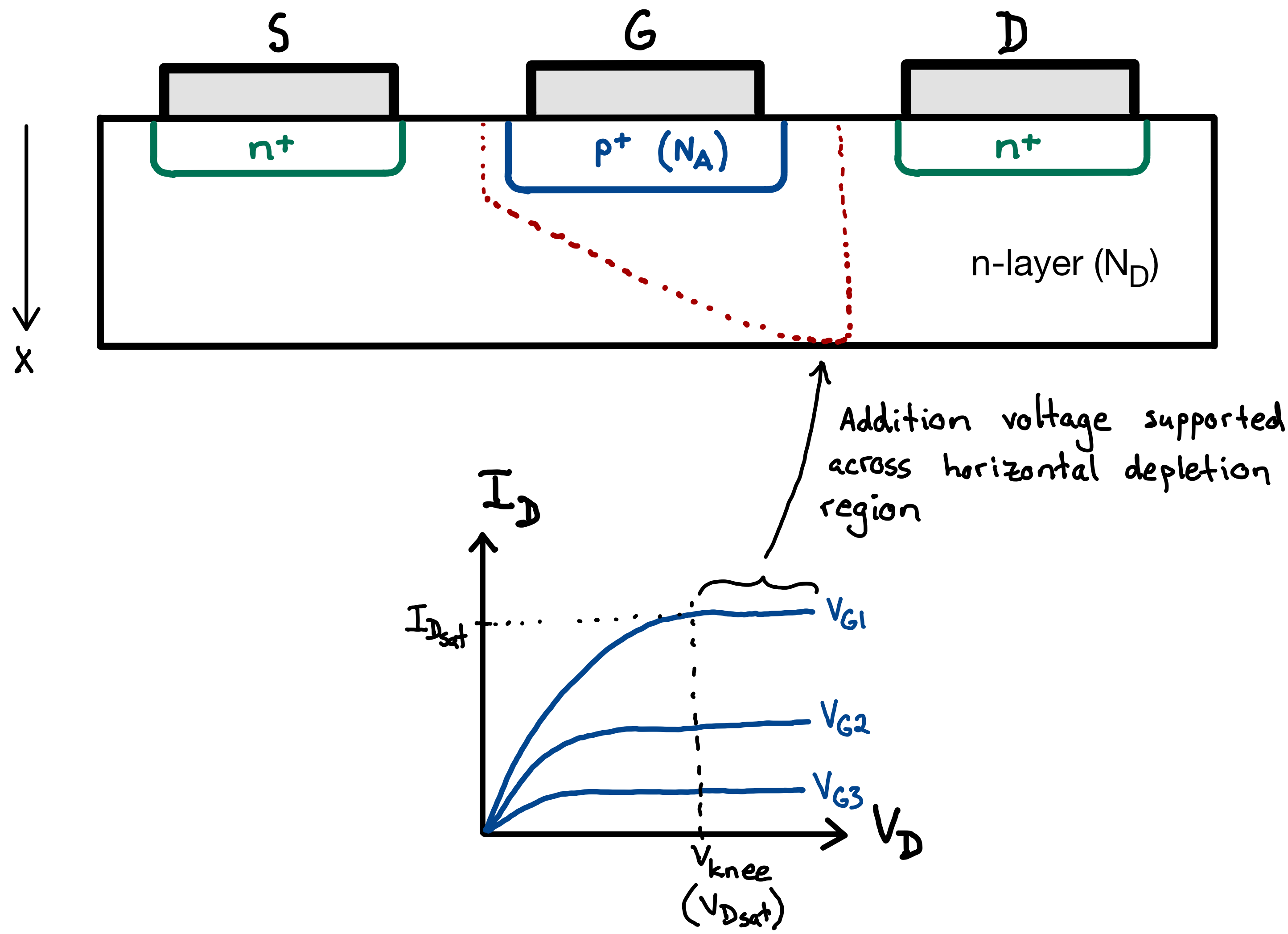
- $$\boxed{V_{knee} = \frac{qN_D t^2}{2\epsilon_s} - V_{bi} + V_G}$$



- $$\boxed{I_{Dsat} = G_0 \left[\frac{qN_D t^2}{6\epsilon_s} - (V_{bi} - V_G) \left\{ 1 - \frac{2}{3} \left[\frac{2\epsilon_s (V_{bi} - V_G)}{qN_D t^2} \right]^{1/2} \right\} \right]}$$

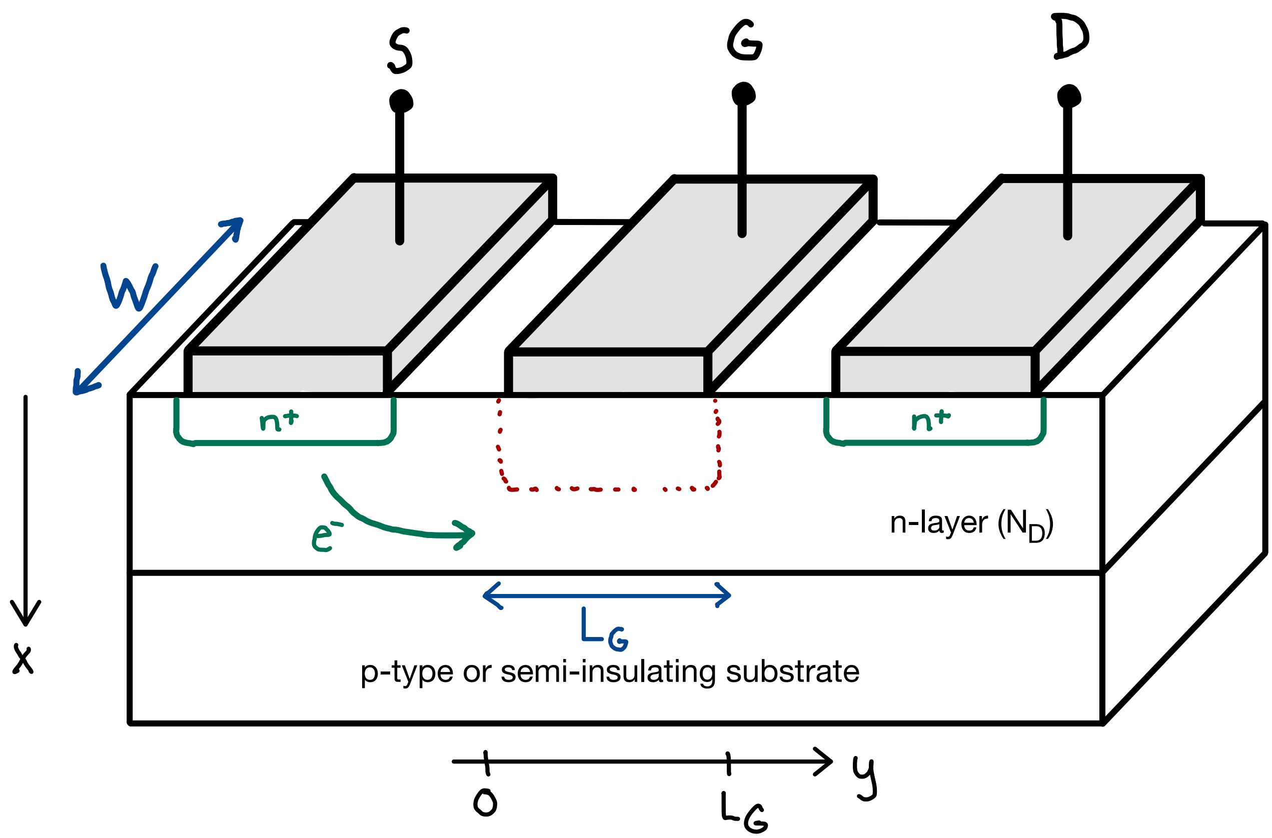
(derivation in Muller/Kamins)

For $V_D > V_{knee}$:

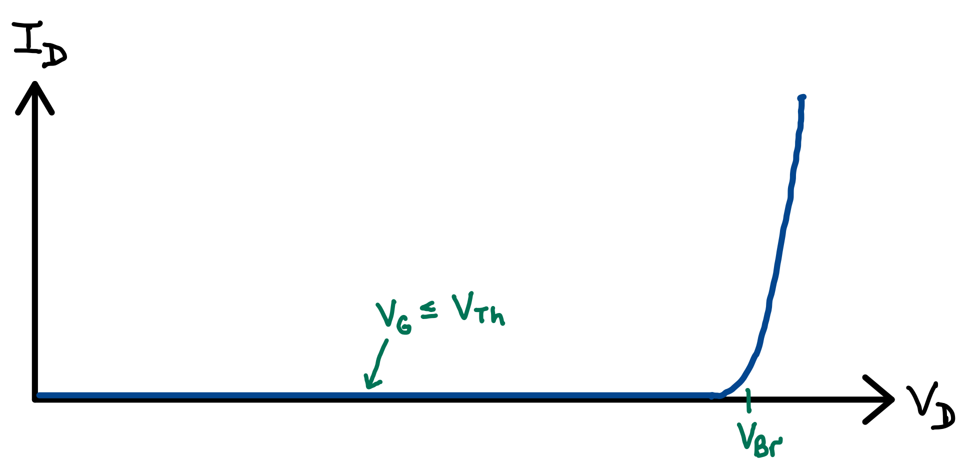


- How to fabricate a JFET

MESFET (Metal-Semiconductor FET)



- I-V characteristics similar to JFET, but different value of V_{bi}
- V_{Br} in a MESFET:



MESFET with a Field Plate