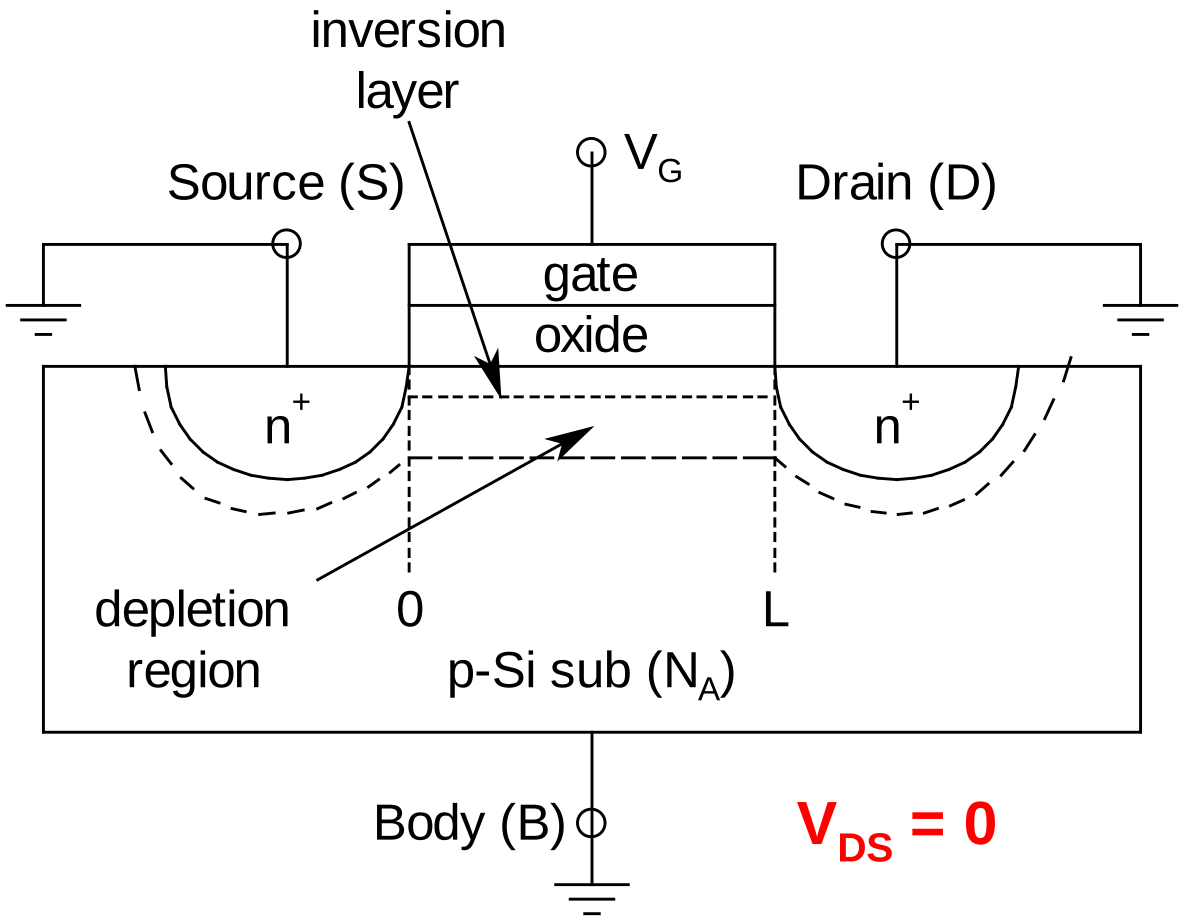
Operation

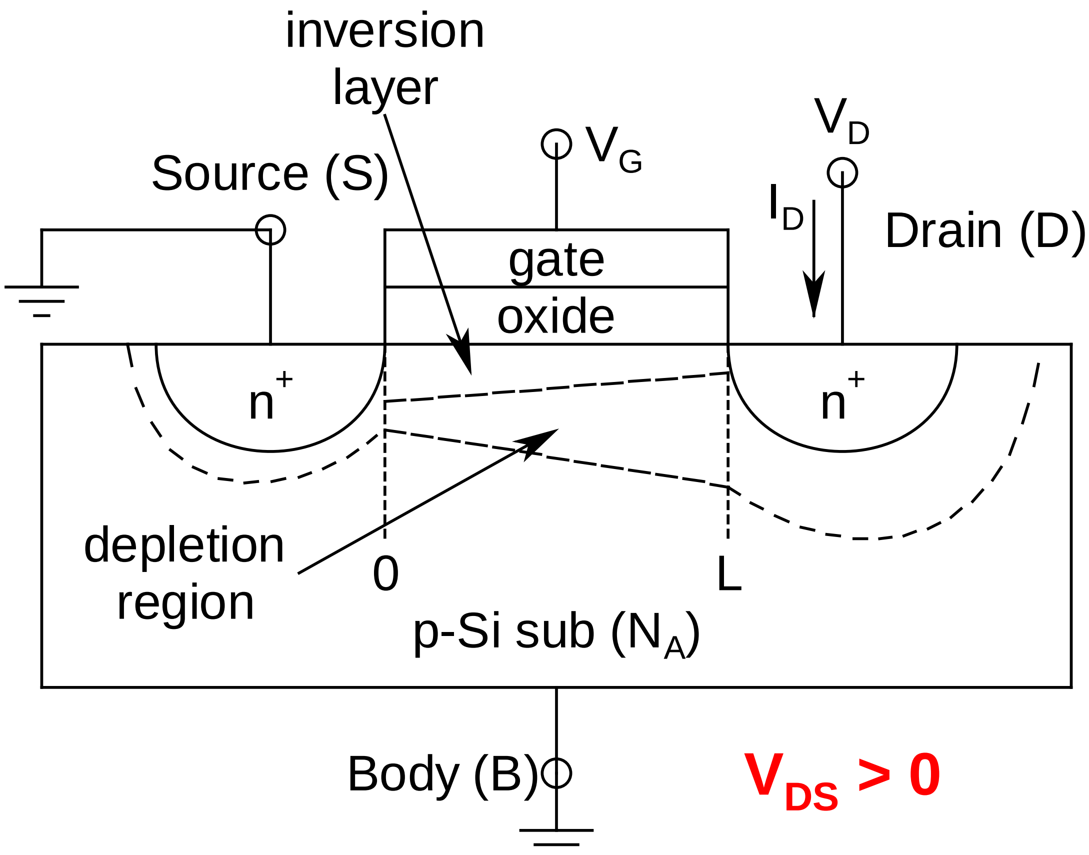


inversion layer
V_G
Source (S)
Drain (D)
gate
oxide
n+
n+
depletion region
0
L
p-Si sub (N_A)
Body (B)
V_DS = 0

- The structure is ***similar*** to an ***n^+pn^+ BJT***
- However, ***BJT action*** is ***not possible*** due to ***large channel length*** (L)
- The way to make the device ***conduct*** is to form a ***layer of electrons*** between S and D
  - Known as ***Inversion Layer***
- Then, if a ***bias*** is applied ***between S and D***, then ***inversion layer electrons*** will move ***towards the higher potential*** due to ***drift***
  - A ***current*** would result

- Consider $V_S = V_D = V_B = V_G = 0$
  - Device is ***off*** and ***no current flows***
- Note that the ***structure*** is similar to a ***capacitor***
- Now, as V_G is made ***positive***, initially it will ***repel holes from surface towards bulk***, ***uncovering ionized acceptor atoms there***
  - ***Formation of a depletion layer***
- There will be ***depletion layers*** around ***SB and DB junctions*** as well

- As V_G is kept on ***increasing***, the ***depletion charge*** will keep on ***increasing***
- At a ***certain value*** of V_G (= V_{GS}), a ***layer of electrons*** will ***appear at the surface***
- This ***particular value*** of V_{GS} is known as the ***threshold voltage*** V_{TN}
- Still ***no current*** would flow, since $V_{DS} = 0$
- ***SB and DB junctions*** must remain ***either at zero bias or reverse bias*** all the time
  - V_{SB} and $V_{DB} \geq 0$


inversion layer
Source (S)
V_G
V_D
I_D
Drain (D)
gate
oxide
n^+
n^+
depletion region
0
L
p-Si sub (N_A)
Body (B)
$V_{DS} > 0$

- With $V_{DS} > 0$, ***inversion layer electrons*** will ***move*** towards the ***higher potential***, i.e., D
  - The ***drain current*** I_D would ***flow from D to S***
- ***Note***:
  - The ***depletion charge*** would ***increase*** as we move ***towards the D*** (since the ***DB junction*** is ***more reverse biased***)
    - The ***inversion charge*** would ***decrease*** as we move ***towards the D*** (to balance the gate charge)
    - For ***sufficiently high*** V_{DS}, it may ***disappear altogether at the drain end***

Body Effect

- The ***threshold voltage*** V_{TN} is a ***function*** of the ***SB voltage*** V_{SB}
- As $V_{SB}\uparrow$, the ***SB junction depletion charge*** would ***increase***
  - ➢ For the ***same*** V_{GS}, ***inversion charge*** would ***decrease*** (to maintain ***charge balance***)
  - ➢ Thus, to ***restore*** the ***original level*** of ***inversion***, V_{GS} has to be ***increased***
  - ➢ Implies that V_{TN} has ***increased***

- Expressed as:

$$V_{TN} = V_{TN0} + \gamma\left(\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F}\right)$$

$$V_{TN0} = V_{TN}\Big|_{V_{SB}=0}$$ = ***Zero back-bias threshold voltage***

$$\gamma = \frac{\sqrt{2q\varepsilon_s N_A}}{C'_{ox}}$$ = ***Body-effect coefficient***

$$C'_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$$ = ***Oxide capacitance per unit area***

$$\phi_F = V_T \ln\left(\frac{N_A}{n_i}\right)$$ = ***Bulk potential*** (~ 0.3 - 0.45 V)

Current-Voltage Relation

- For $V_{GS} > V_{TN}$ and ***small*** V_{DS}:

$$I_D = k_N \left(V_{GT} V_{DS} - V_{DS}^2 / 2 \right)$$

$$V_{GT} = V_{GS} - V_{TN} = \textit{Gate overdrive}$$

$$k_N = \left(W/L \right) k'_N$$

$$= \textbf{\textit{Device transconductance parameter}}$$

$$W/L = \textit{Aspect ratio}$$

$$k'_N = \mu_n C'_{ox}$$

$$= \textit{Process transconductance parameter}$$

μ_n = ***Channel electron mobility***

- For ***small*** V_{DS}, the V_{DS}^2 term can be ***neglected***
  - ➢ I_D changes ***linearly*** with V_{DS}
    - ***Linear*** (or ***Non-Saturation***) Region
- As $V_{DS}\uparrow$, the ***restraining*** effect of V_{DS}^2 term$\uparrow$
  - ➢ ***Rate of increase*** of I_D with V_{DS} ***slows down***

- For ***inversion channel*** to exist at the ***D end***, ***V_{GD} must be > V_{TN}***
  - ***V_{DS} must be < V_{GT}***
- When ***V_{DS} = V_{GT}***, the ***channel*** is said to be ***pinched-off*** at the ***D end***, and ***I_D does not increase any more***
- This value of V_{DS} is known as the ***drain-to-source saturation voltage*** $V_{DS,sat}$
  - $V_{DS,sat} = V_{GT}$