UCLA

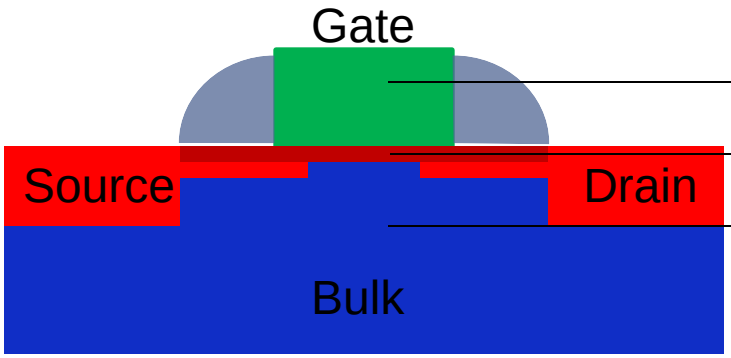
An introduction on MOSFET

14th Oct 2009

Outline

- MOSFET structure
- MOSFET operation
- Small dimension effects

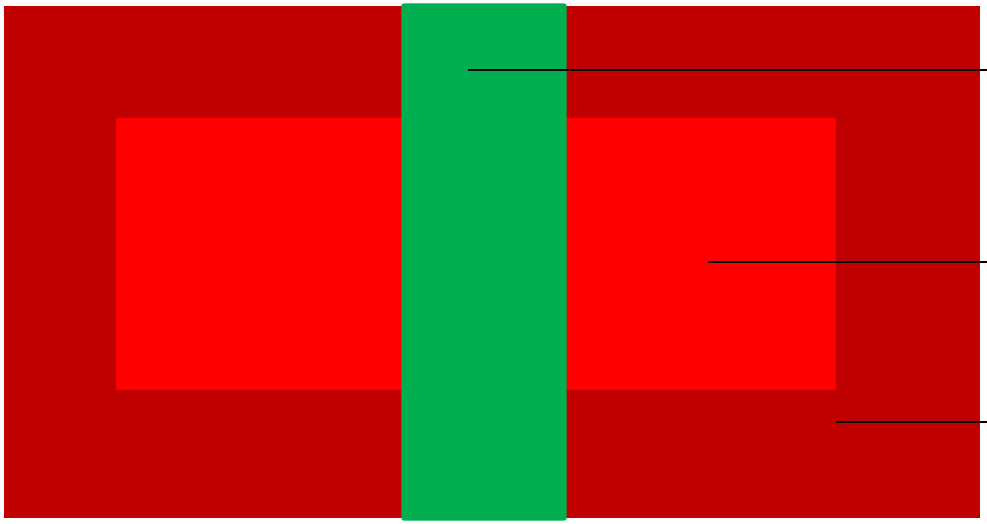
MOS: Metal Oxide semiconductor



Metal

Oxide

Semiconductor

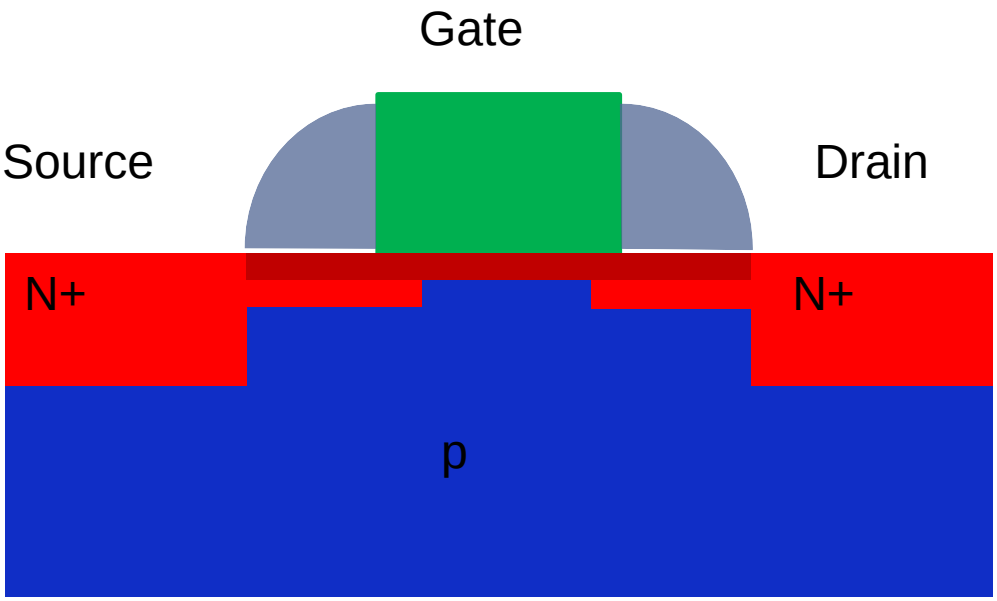


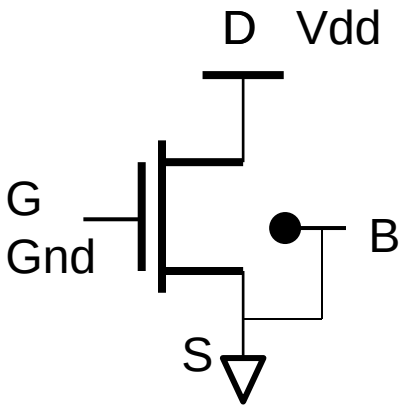
Polysilicon

Active region

Oxide (STI)

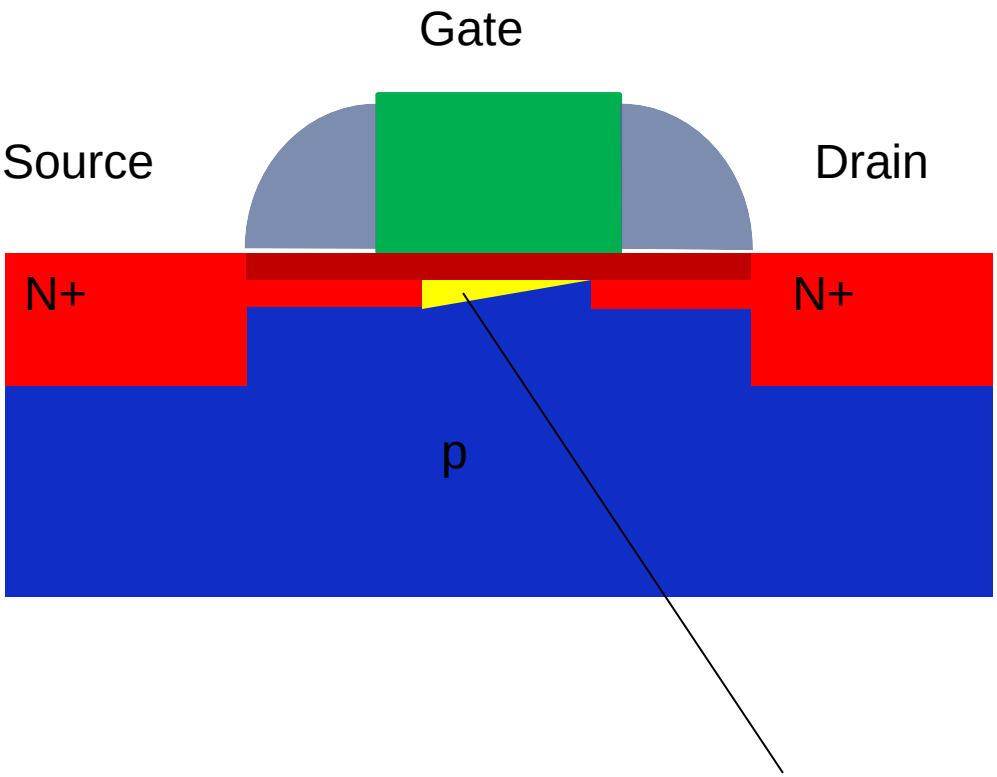
NMOS - off

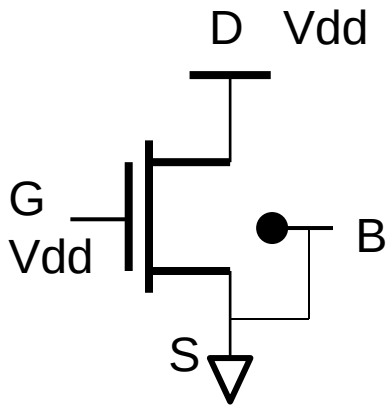




- No inversion layer in channel.
- No drive (drift) current.
- Only leakage current (from gate and drain terminals).

NMOS – on (saturation)





- When $V_{gs} > V_{th}$, an inversion layer is formed.

Modes of operation

- Cutoff
  - ($V_{gs} < V_{th}$)

$$I_d = I_0 e^{\frac{V_{gs}-V_{th}}{nV_T}}$$

- Saturation
  - $V_{GS} > V_{th}$
    $V_{DS} > (V_{GS} - V_{th})$

$$I_d = \frac{\mu_n C_{ox} W}{2L}\left(V_{gs}-V_{th}\right)^2$$

- Linear region
  - $V_{GS} > V_{th}$
    $V_{DS} < (V_{GS} - V_{th})$

$$I_d = \mu_n C_{ox}\frac{W}{L}\left(\left(V_{gs}-V_{th}\right)V_{ds}-\frac{V_{ds}^{\ 2}}{2}\right)$$

Body effect

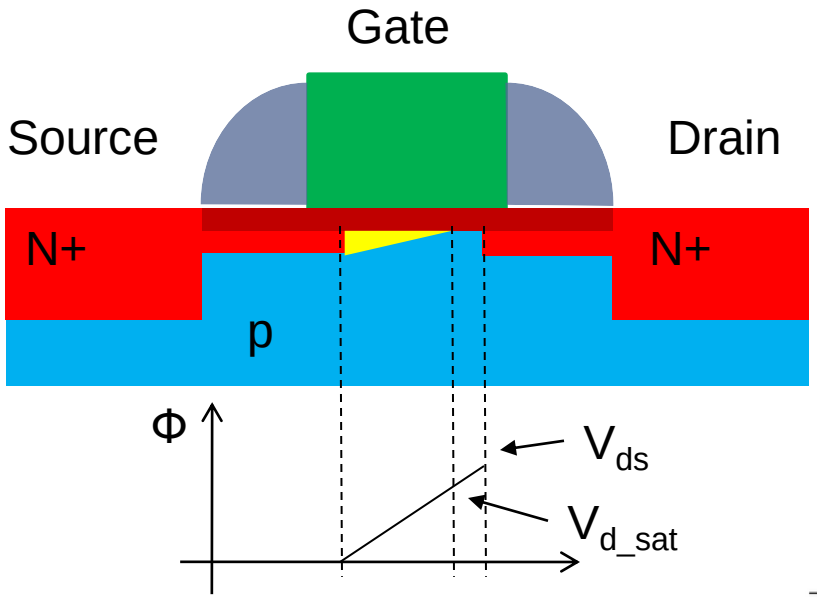
- $V_{th}= V_{th0}+ \gamma[(V_{sb}+2\Phi)^{0.5}-(2\Phi)^{0.5}]$

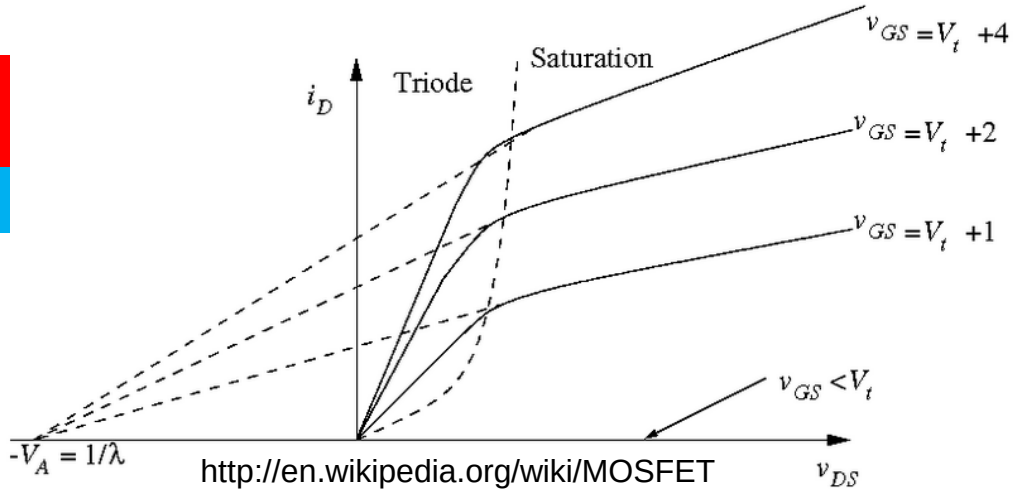
Channel length modulation

- L effective reduce when $V_d > V_{d\_sat}$

$$I_d = \frac{\mu_n C_{ox} W}{2L'}\left(V_{gs} - V_{th}\right)^2, L' = L - \Delta L$$

$$I_d = I_{d\_sat}\left(\frac{L}{L-\Delta L}\right) \approx I_{d\_sat}\left(1+\frac{\Delta L}{L}\right)$$

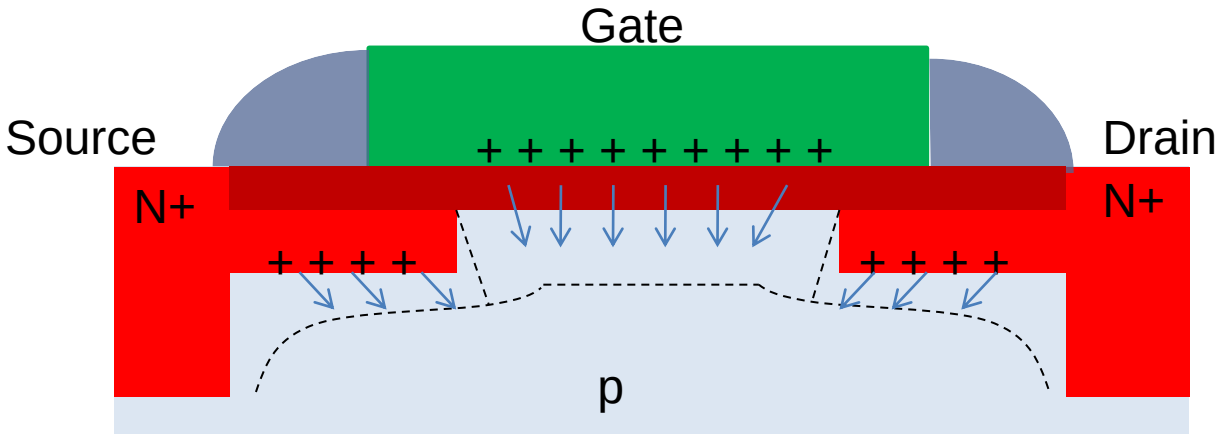


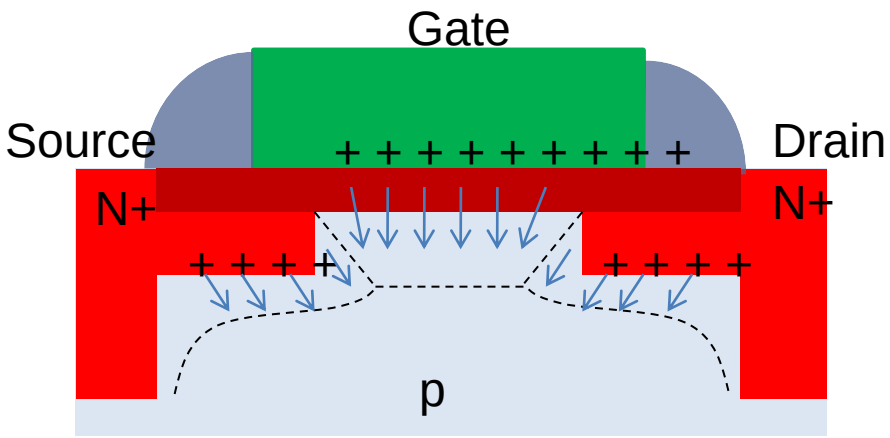


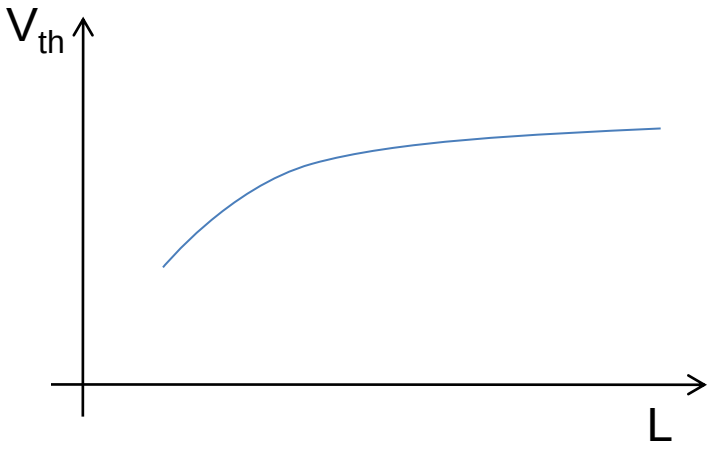
http://en.wikipedia.org/wiki/MOSFET

Short channel effects

- Charge sharing

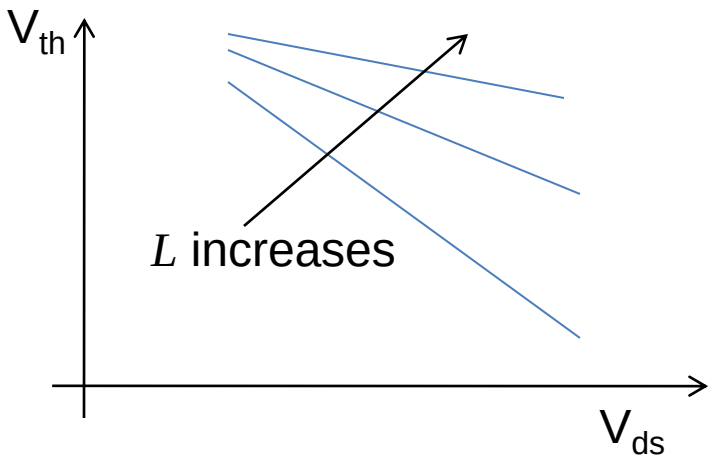


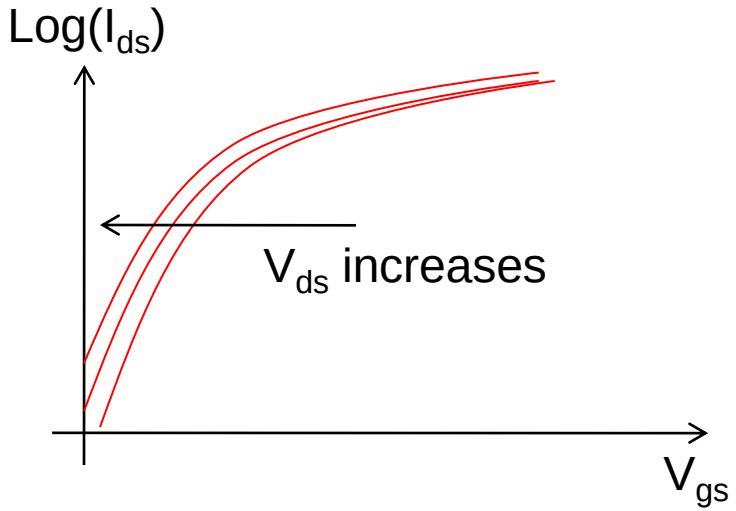




Drain-induced barrier lowering (DIBL)

- Drain voltage “pull down” electron barrier.
- V_{th} depends on both L and V_{ds}.

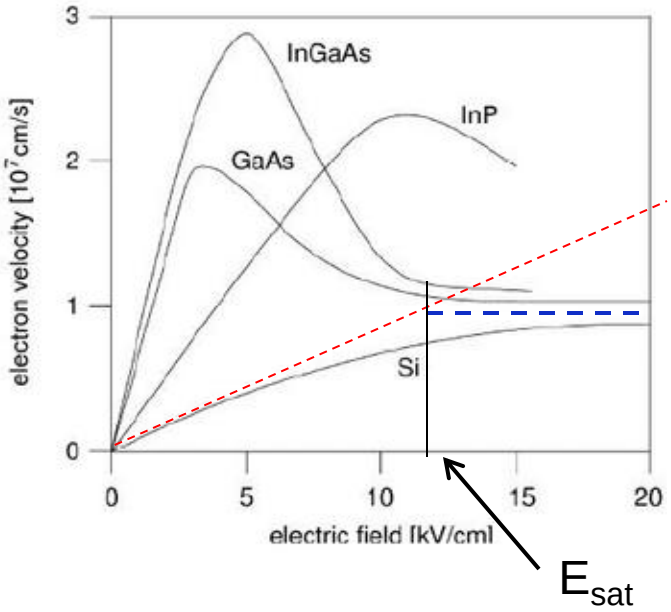




Velocity saturation

$$v = \mu_{eff} E, \quad \text{Valid only when E << } E_{sat}$$

$$v = \frac{\mu_{eff} E}{(1 + E / E_{sat})}$$



No velocity saturation

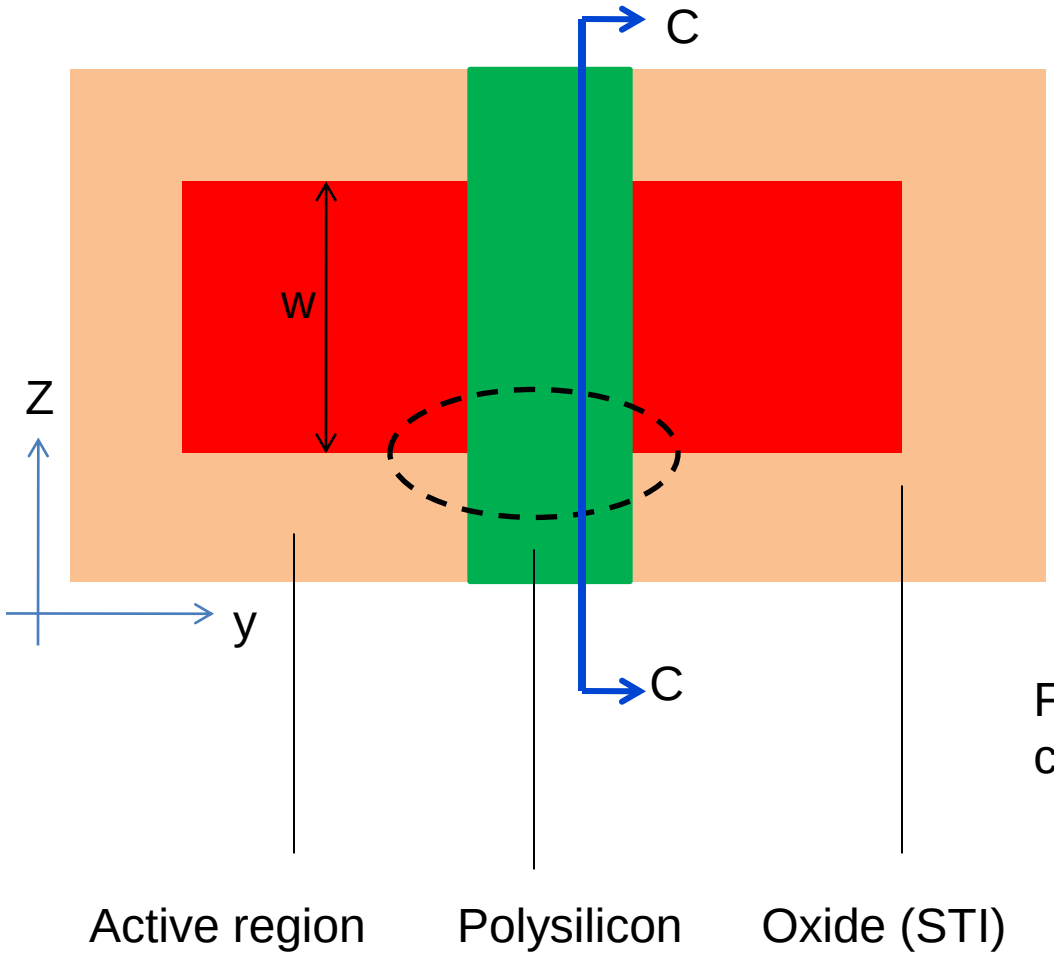
$$I_d = \mu_n C_{ox} \frac{W}{L}\left((V_{gs} - V_{th})V_{ds} - \frac{V_{ds}^2}{2}\right)$$

With velocity saturation***

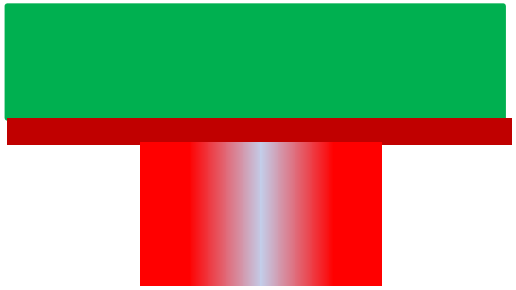
$$I_d = \mu_{eff} C_{ox} \frac{W}{L}\left((V_{gs} - V_{th})V_{ds} - \frac{V_{ds}^2}{2}\right)\left(\frac{1}{1 + (V_{ds} / E_{sat} L)}\right)$$

***μ_{eff} and V_{th} are treated as constants across channel.

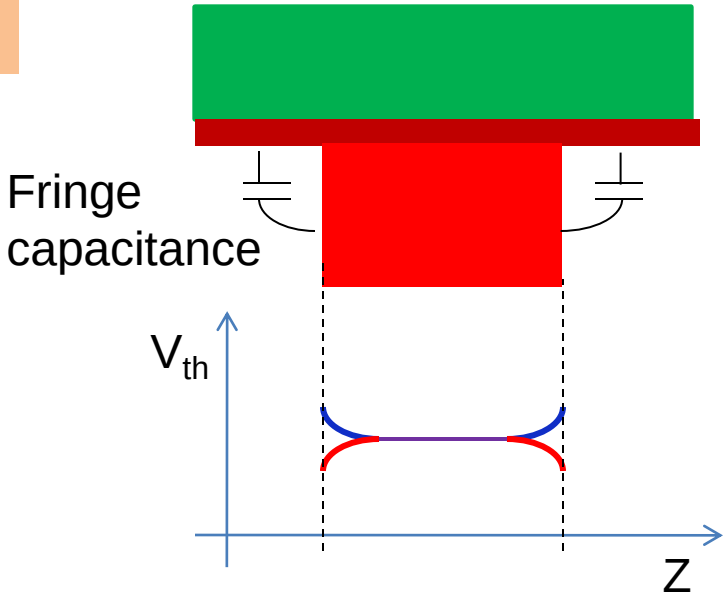
Narrow width effects



Cross section along C



Non-uniform doping



References

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2. Y.-M. Sheu, K.-W. Su, S. Tian, S.-J. Yang, C.-C. Wang, M.-J. Chen, *and S. Liu, “*Modeling the Well-Edge Proximity Effect in Highly Scaled MOSFETs”, IEEE Trans. On Electron Devices, vol. 53, no. 11, 2006.
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