Advanced MOSFETs and Novel Devices

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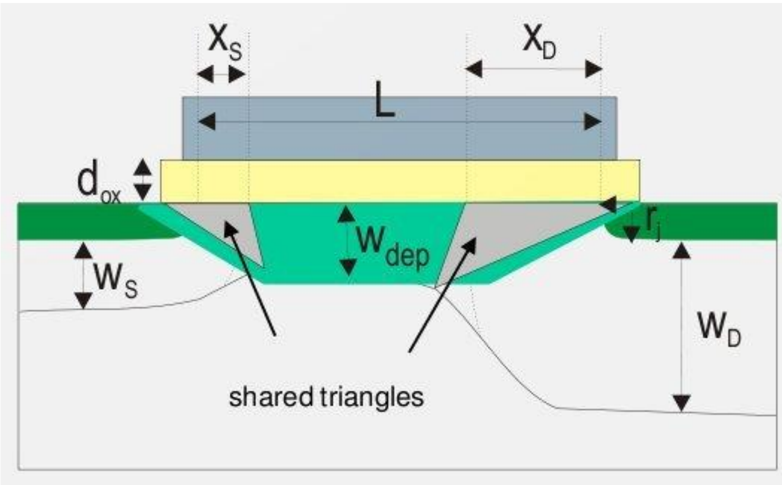
5. Tutorial & Exercise

Short Channel Effects

Short channel and the contribution of S/D depletion is high:
(very short channel and/or V_{DS} high)



1) with high V_{DS} the shared triangles increase to unsymmetrical triangles:

$$x_S = \sqrt{\frac{2\epsilon_0\epsilon_{Si}\cdot(V_{bi}-\Psi_S)}{qN_A}} \approx \sqrt{\frac{2\epsilon_0\epsilon_{Si}\cdot(V_{bi}-2\Psi_B)}{qN_A}}$$

$$x_D = \sqrt{\frac{2\epsilon_0\epsilon_{Si}\cdot(V_{bi}-\Psi_S+V_{DS})}{qN_A}} \approx \sqrt{\frac{2\epsilon_0\epsilon_{Si}\cdot(V_{bi}-2\Psi_B+V_{DS})}{qN_A}}$$

keeping $\Psi_S = 2\ \Psi_{bulk}$ approximately constant -> w_c~const $w_{dep} = \sqrt{\frac{2\epsilon_0\epsilon_{Si}\cdot 2|\Psi_B|}{qN_A}}$

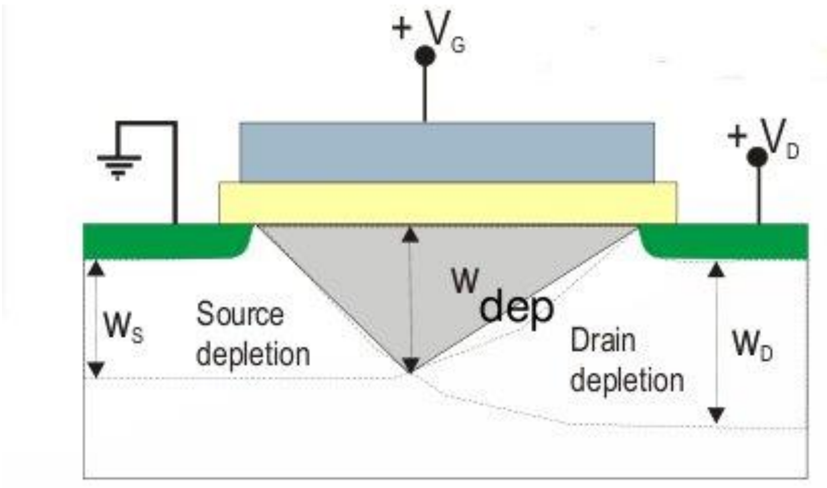
2) the threshold voltage shift is then:

+ :p-channel
- :n-channel

SC: Short Channel
LC: Long Channel

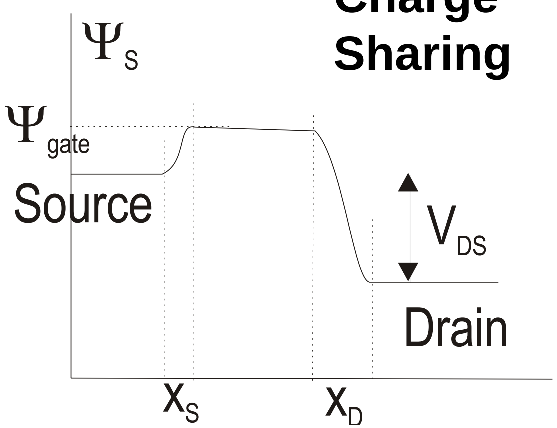
$$\Delta V_T = V_T^{new} - V_T^{old} = V_T^{SC} - V_T^{LC} = \pm\frac{|q|N_A w_{dep}\cdot r_j}{2LC''_{Ox}}\cdot\left[\left(\sqrt{1+\frac{2x_S}{r_j}}-1\right)+\left(\sqrt{1+\frac{2x_D}{r_j}}-1\right)\right]$$

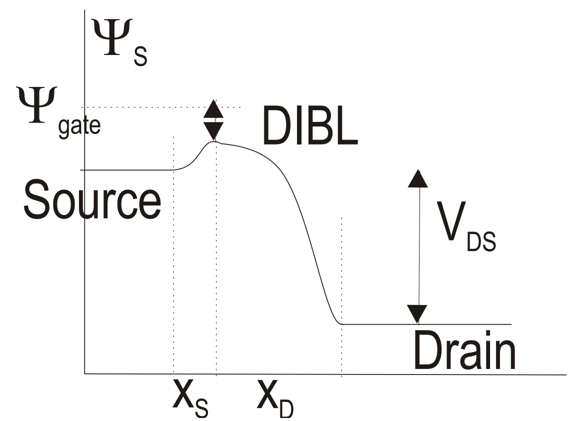
Drain Induced Barrier Lowering



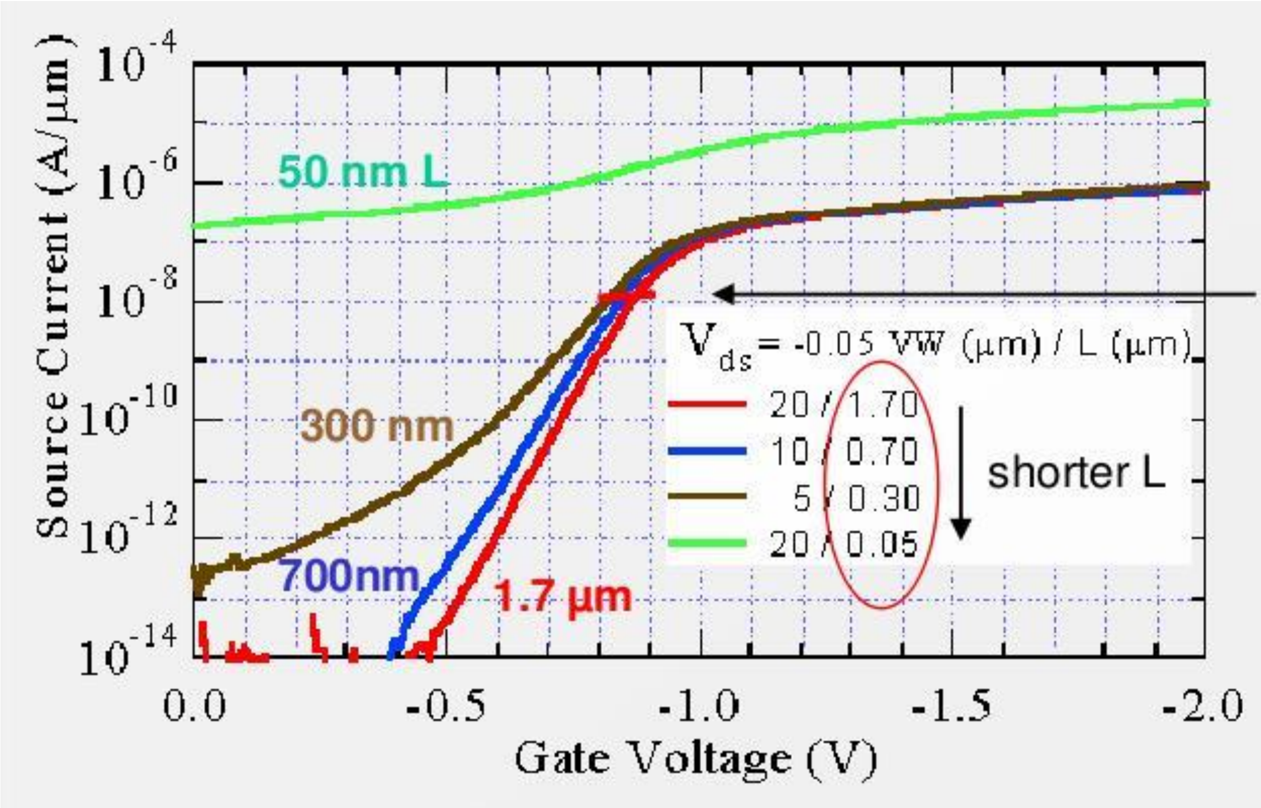
Short channel and the contribution of S/D depletion is very high
(stronger dependence of V_T on V_{DS})

Charge Sharing





SCE – V_T roll off



Shrinking MOSFET

Channel length reduced

Shift in threshold voltage for different MOSFETs

An IC manufacturer wants to minimize the development costs for technology and decides to shrink nothing besides the lateral dimensions (channel length and width).

- Determine a more realistic value of the threshold voltage V_T for the *p*-channel MOSFET of the 180 nm technology node from the previous tutorial using the charge sharing model and the BSIM4 model (Spice).
- Calculate the V_T roll-off for the next two scaling steps ($S_1=\sqrt{2}$, $S_2=2$).

$V_{DS}=-V_{DD}$, neglect fixed and trapped oxide charges.

Technology parameters:

V_{DD}	d_{OX}	N_D	L	W	N_A	r_j
1.8 V	3 nm	1e18 cm^{-3}	140 nm	3*L	1e20 cm^{-3}	40 nm

SCE - Exercise

V_{DD}	d_{OX}	N_D	L	W	N_A	r_j
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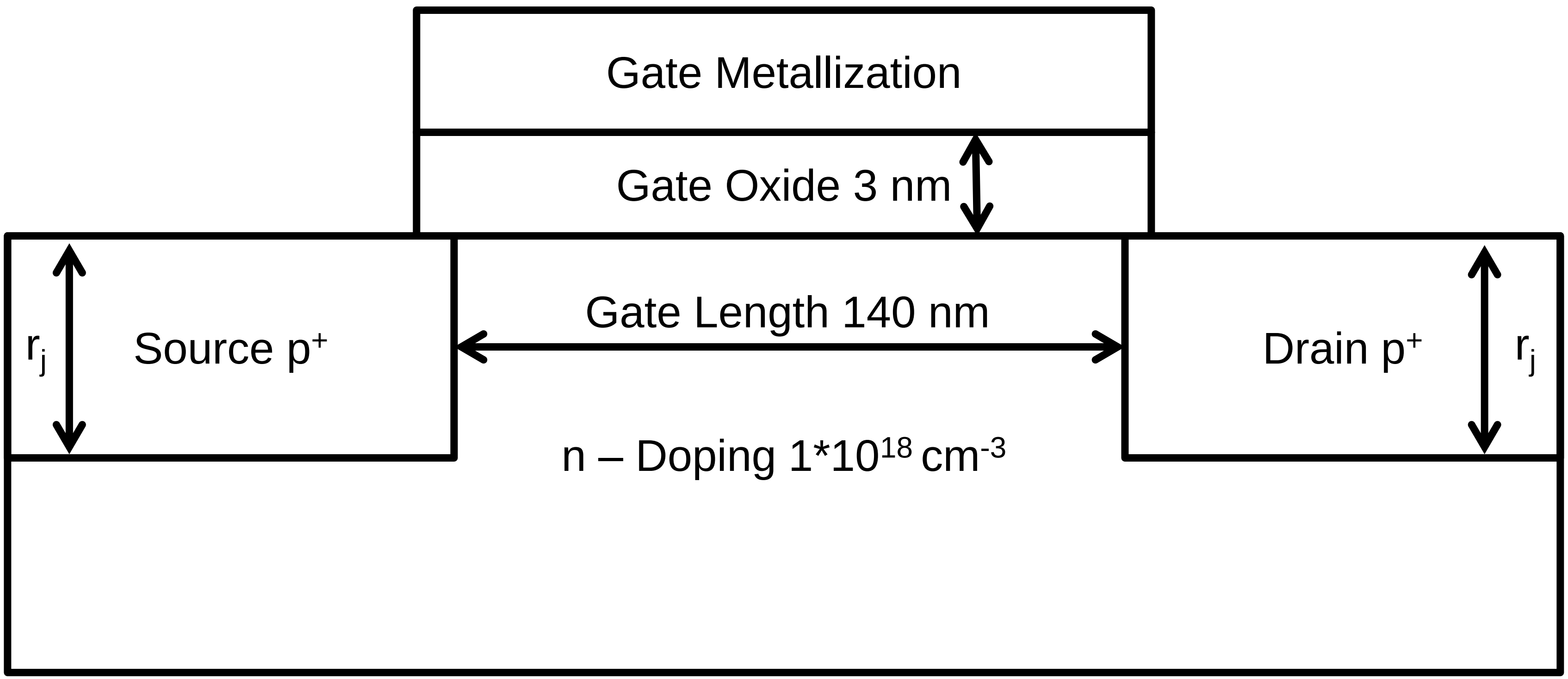

2.4 Short-Channel and DIBL Effects

As channel length becomes shorter, V_{th} shows a greater dependence on channel length (SCE: short-channel effect) and drain bias (DIBL: drain induced barrier lowering). V_{th} dependence on the body bias becomes weaker as channel length becomes shorter, because the body bias has weaker control of the depletion region. Based on the quasi 2D solution of the Poisson equation, V_{th} change due to SCE and DIBL is modeled [4]

$$\Delta V_{th}\left(SCE, DIBL\right) = -\theta_{th}\left(L_{eff}\right)\cdot\left[2\left(V_{bi}-\Phi_{s}\right)+V_{ds}\right] \tag{2.23}$$

where V_{bi}, known as the built-in voltage of the source/drain junctions, is given by

SCE – Charge Sharing

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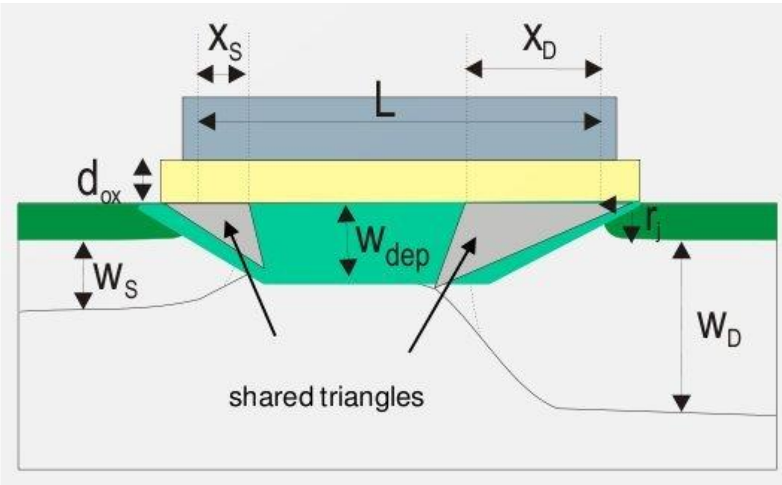

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Depletion Zone: $x \quad = x_D + x_S = 62.9\ nm$

L	SCE	DIBL	
140 nm			
100 nm			
70 nm			

- For L = 140 nm: SCE is the better model because a remarkable part of the channel is not occupied by Source/Drain
- For L = 70 nm: DIBL is the better model because the Source/Drain depletion zones occupy a remarkable part of the channel