Semiconductor Materials and Devices
(반도체 재료 및 소자)

Chapter 11. Additional concepts

Young Min Song

Assistant Professor

School of Electrical Engineering and Computer Science

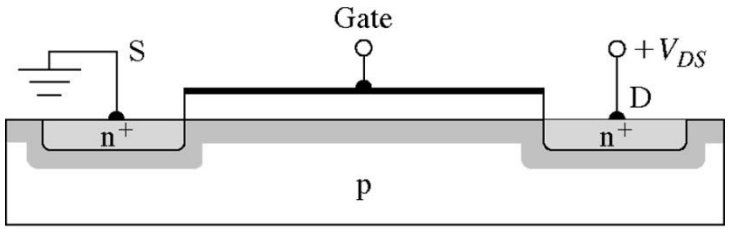
Gwangju Institute of Science and Technology

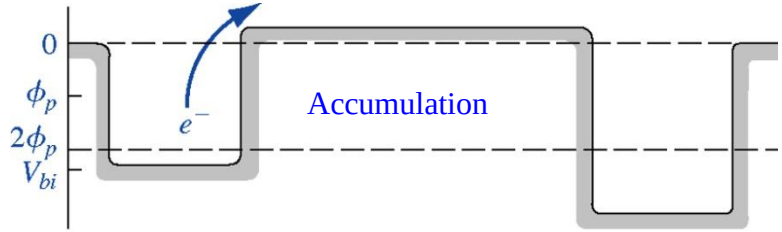
http://www.gist-foel.net

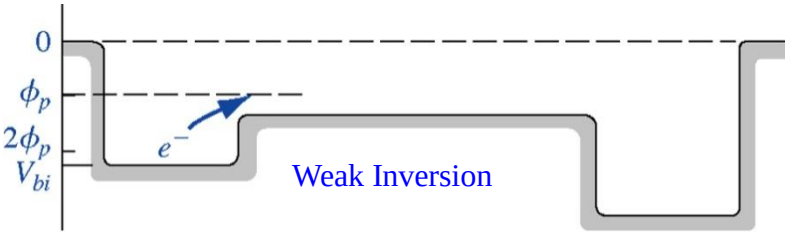
ymsong@gist.ac.kr, ymsong81@gmail.com

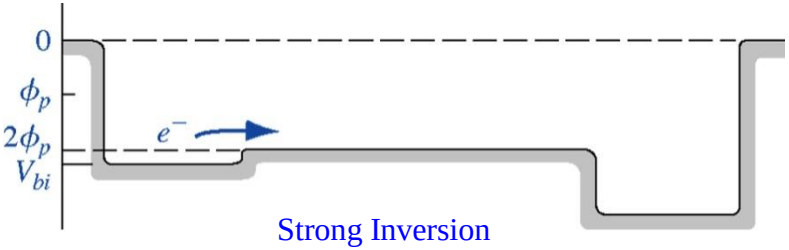
A207, ☎2655

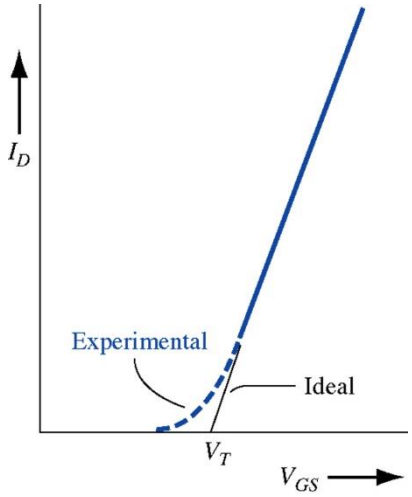
Subthreshold Conduction

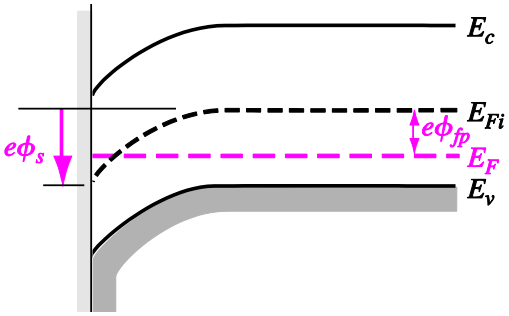








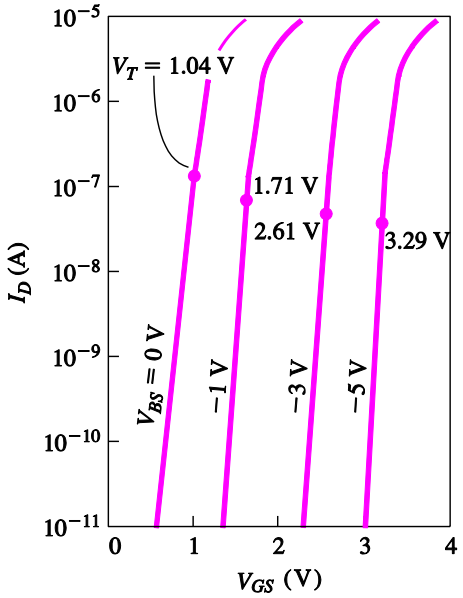




Subthreshold current :

$\phi_{fp} < \phi_s < 2\phi_{fp}$

$$I_D(\text{sub}) \propto \left[\exp\left(\frac{eV_{GS}}{kT}\right)\right] \cdot \left[1 - \exp\left(\frac{-eV_{DS}}{kT}\right)\right]$$



Subthreshold current with different substrate bias voltages.

Subthreshold Swing

(SS : mV/decade)

: Gate voltage required to increase the subthreshold current ten times larger.

Channel Length Modulation

$$x_p = \sqrt{\frac{2\epsilon_s \phi_{fp}}{eN_a}} \Rightarrow x_p = \sqrt{\frac{2\epsilon_s}{eN_a}(\phi_{fp} + V_{DS})}$$

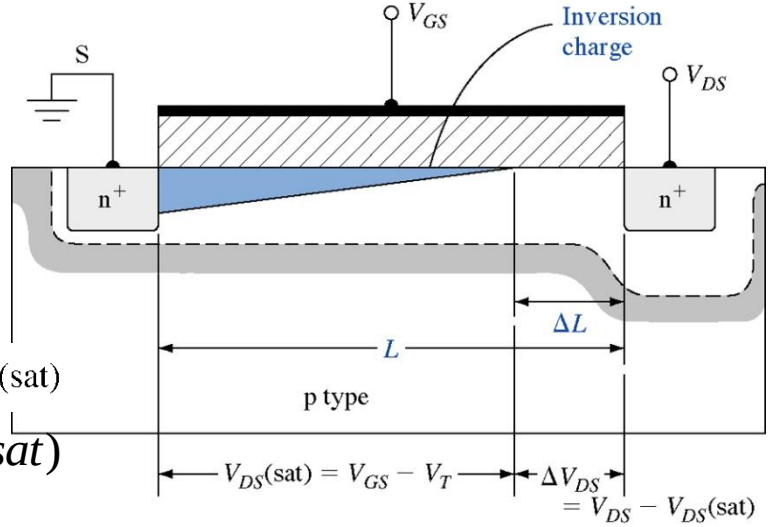
With V_{DS} at drain side

$$\Delta L = \sqrt{\frac{2\epsilon_s}{eN_a}}\left[\sqrt{\phi_{fp} + V_{DS}(\text{sat}) + \Delta V_{DS}} - \sqrt{\phi_{fp} + V_{DS}(\text{sat})}\right]$$

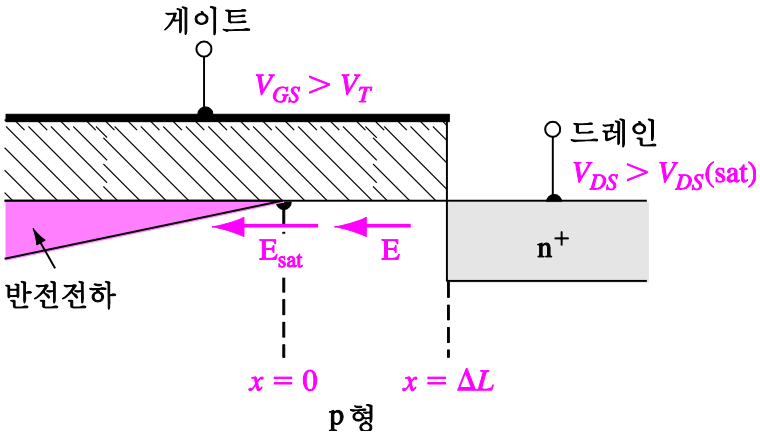
$$\Delta L = \sqrt{\frac{2\epsilon_s}{eN_a}}\left[\sqrt{\phi_{\text{sat}} + (V_{DS} - V_{DS}(\text{sat}))} - \sqrt{\phi_{\text{sat}}}\right]$$

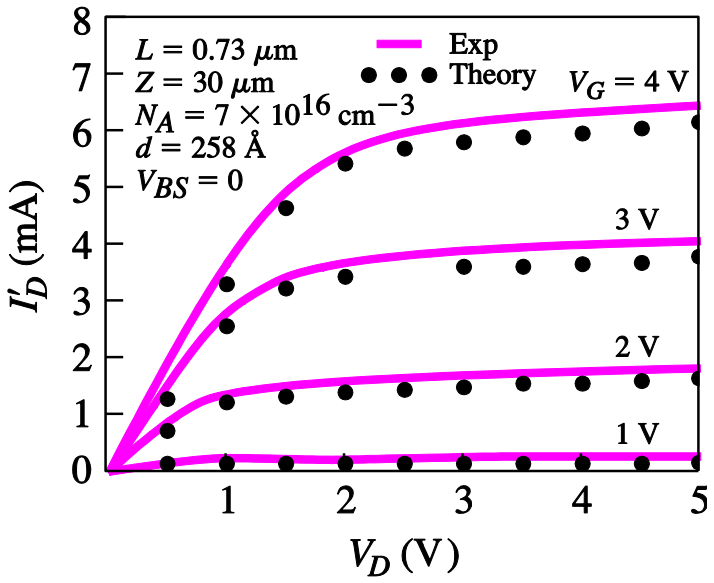
$$\Delta V_{DS} = V_{DS} - V_{DS}(\text{sat})$$

$$\phi_{sat} = \phi_{fp} + V_{DS}(sat)$$



$$I'_D = \left(\frac{L}{L - \Delta L}\right) I_D$$



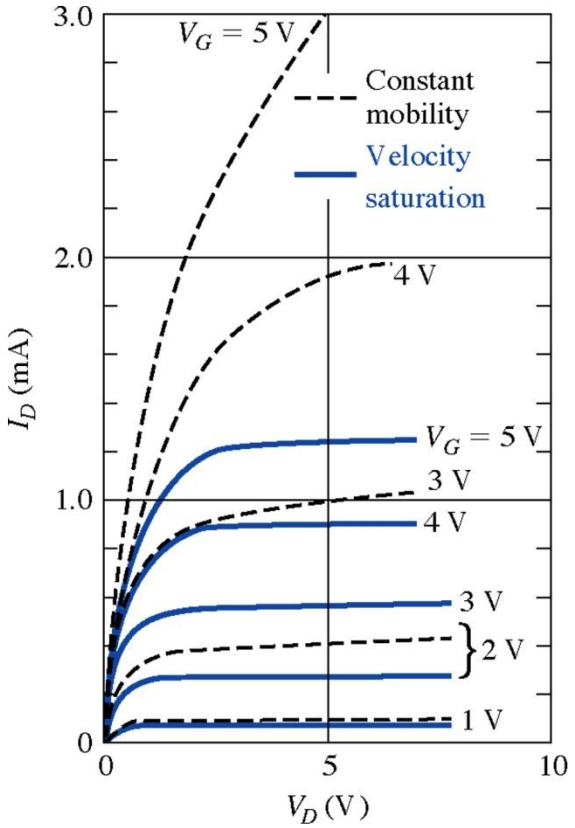


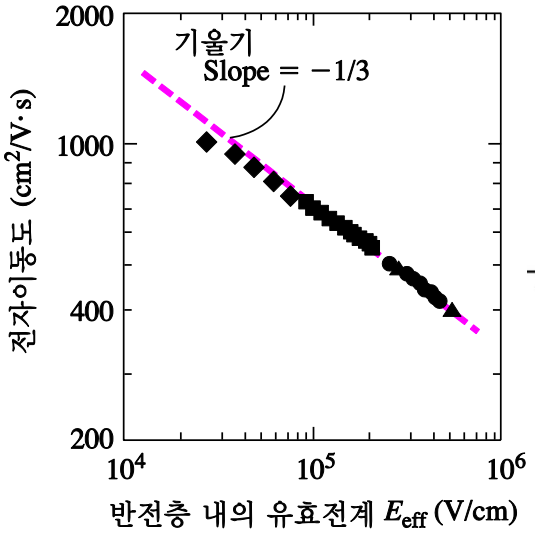
Mobility Variation and Drift Velocity Saturation

Mobility is NOT constant

-Surface scattering due to vertical gate electric field

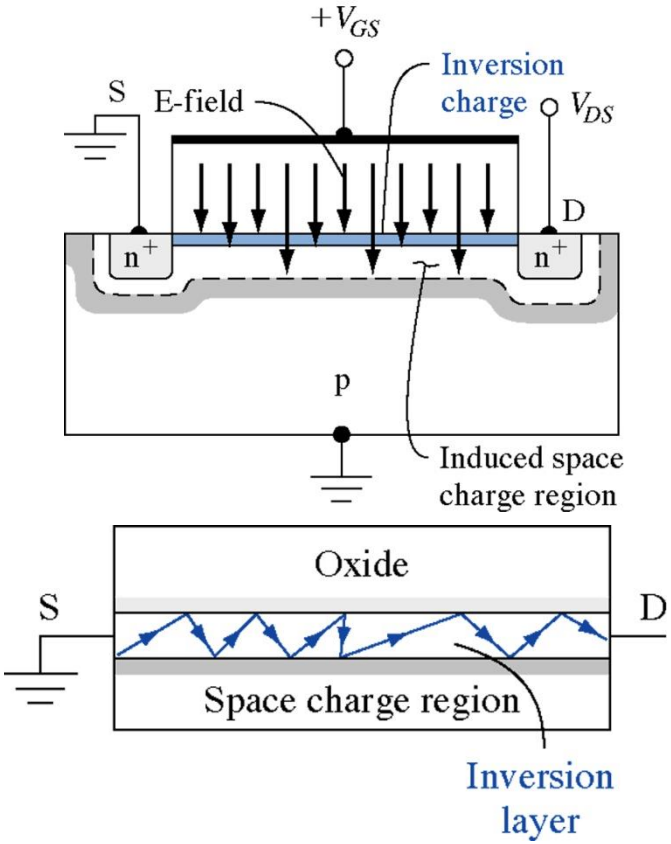
-Carrier drift velocity saturation





$$\mu_{eff} = \mu_0 \left(\frac{E_{eff}}{E_0} \right)^{-1/3}$$

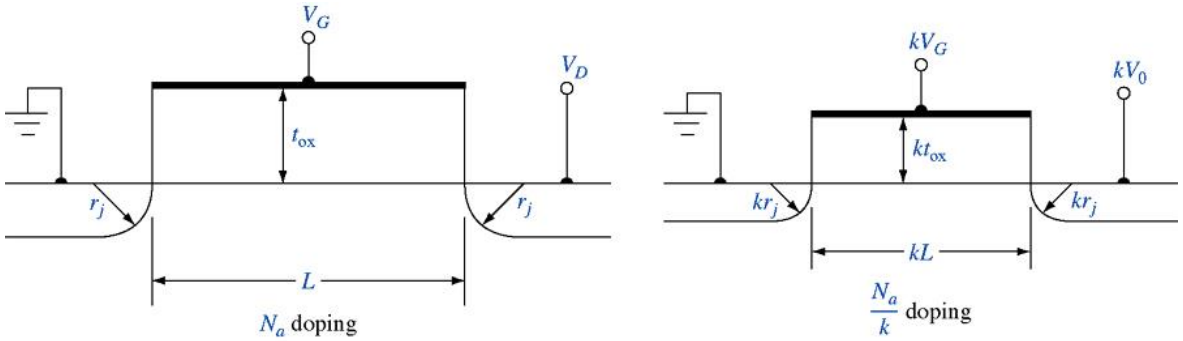
$$I_D(\text{sat}) = WC_{ox}(V_{GS} - V_T)\upsilon_{sat}$$



What other parameters must be scaled as the channel length is scaled down ?

Constant-Field Scaling

Device dimensions and device voltages be scaled such that electric field (both horizontal and vertical) remains essentially constant.



For the depletion length to be scaled, substrate doping should be inversely scaled.

$$x_D = \sqrt{\frac{2\epsilon(V_{bi} + V_D)}{eN_a}}$$

As the channel width is reduced by k , then the drain current is also reduced by k .

$$\frac{I_D}{W} = \frac{\mu_n \epsilon_{ox}}{2t_{ox}L}(V_G - V_T)^2 \rightarrow \frac{\mu_n \epsilon_{ox}}{2(kt_{ox})(kL)}(kV_G - V_T)^2$$

Threshold voltage does not scale directly with the scaling factor k .

$$V_T = \underline{V_{FB} + 2\phi_{fp}} + \frac{\sqrt{2\epsilon e N_a (2\phi_{fp})}}{C_{ox}}$$

: depend on the materials

In reality, electric field tend to increase as device dimension shrink.

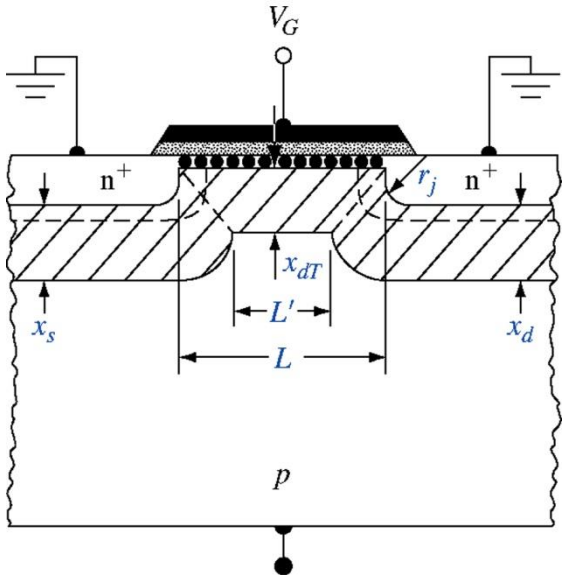
	소자와 회로 파라미터	비례인자 ($k < 1$)
스케일된 파라미터	소자 넓이 (L, t_{ox}, W, x_j)	k
	도핑농도 (N_a, N_d)	$1/k$
	전압	k
소자 파라미터의 영향	전계	1
	캐리어 속도	1
	공핍층 폭	k
	커패시턴스 $(C = \epsilon A/t)$	k
	드리프트 전류	k
회로 파라미터의 영향	소자 밀도	$1/k^2$
	전력 밀도	1
	소자당 전력소비 $(P = VI)$	k^2
	회로 지연 시간 $(\approx CV/I)$	k
	전력 지연 곱 $(P\tau)$	k^3

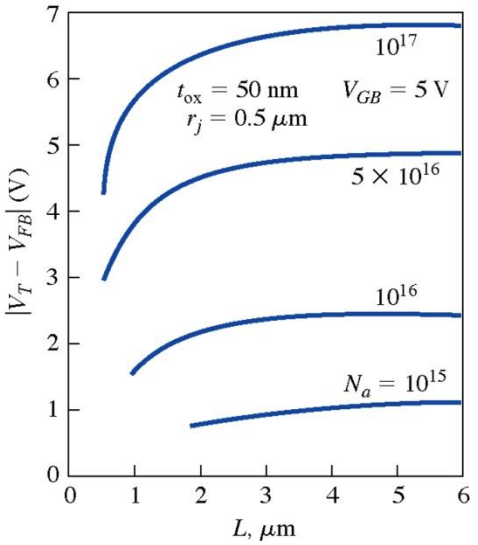
출처:Taur and Ning (1998).

Short-Channel Effects

As the channel length decreases, the threshold voltage shifts in the negative direction.

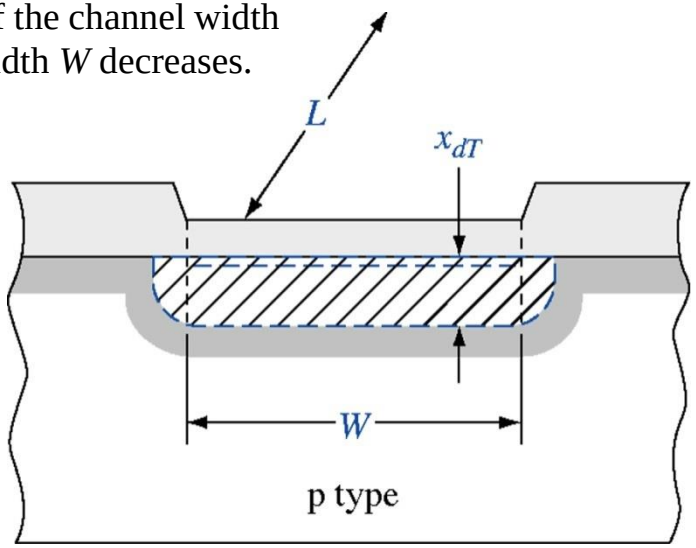
Channel depletion charge is shared by source/drain junction depletion charge

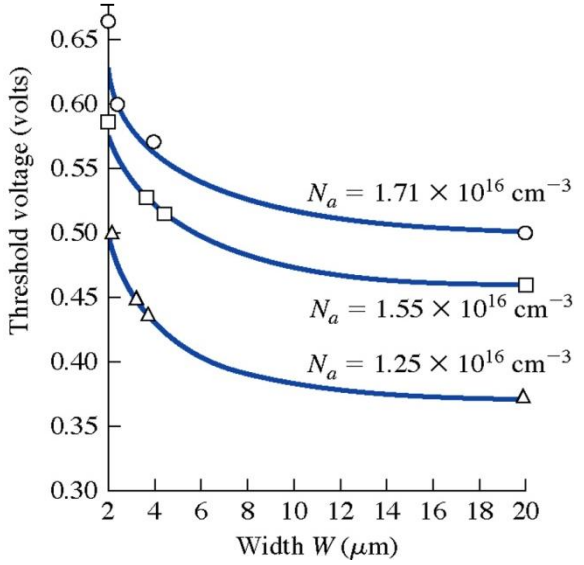




Narrow-Channel Effects

The effect of the end space of the channel width becomes significant as the width W decreases.





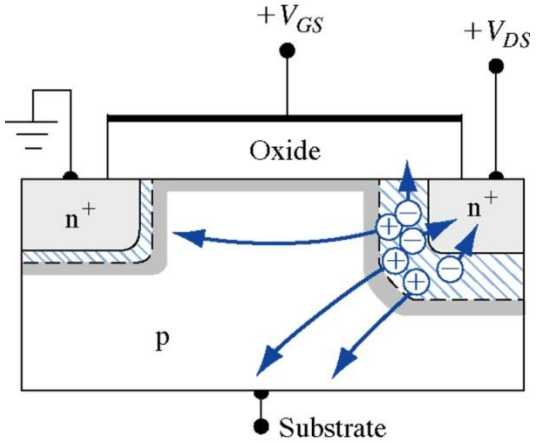
Breakdown in MOSFET

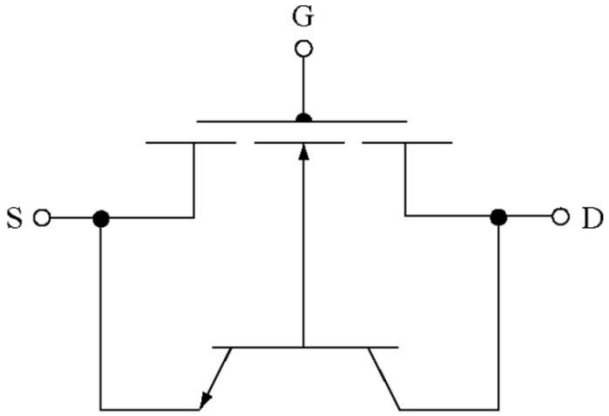
Oxide Breakdown : Over 6x10^6 V/cm → V_{bv} of 20Å thick oxide is 1.2 V .

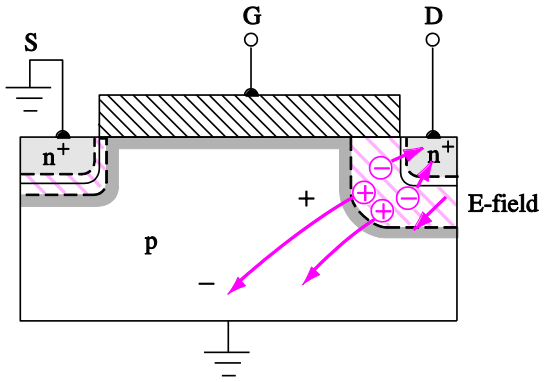
Avalanche Breakdown in the drain corner :

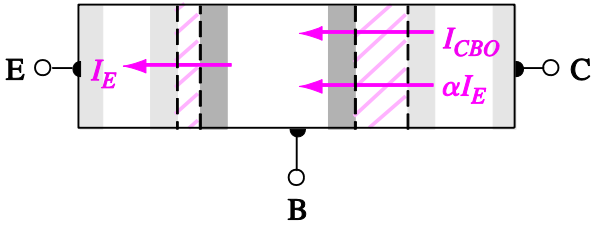
V_{bv} with N_{sub} = 3x10^{16} cm^{-3} is less than 25 V .

Snapback Breakdown : Forward active Turn-on of Parasitic Bipolar transistor (EBC : source-body-drain)









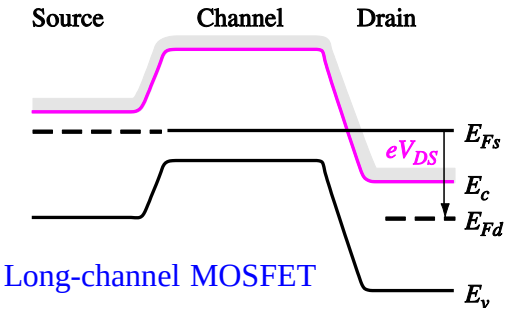
Avalanche-generated reverse current in drain-side depletion area increases the voltage of substrate near source area.

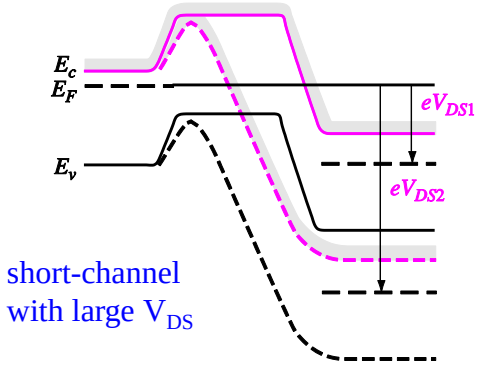
→ The increased substrate (p-type) voltage make the p-n junction (sub-to-source) turn on and injected electrons from the source are diffused into drain to increase the drain current further.

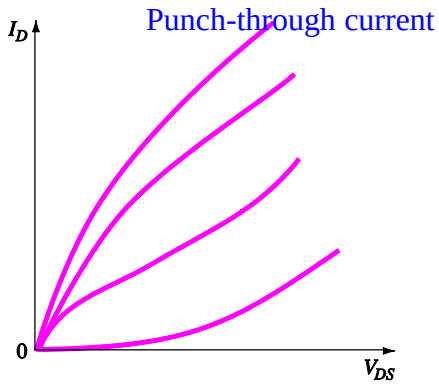
Punch-through Effects and Drain-Induced-Barrier-Lowering

Punch-through : Current can flow through the very closed (or contacted) source and drain depletion regions in the MOSFET with lightly doped substrate and short channel length.

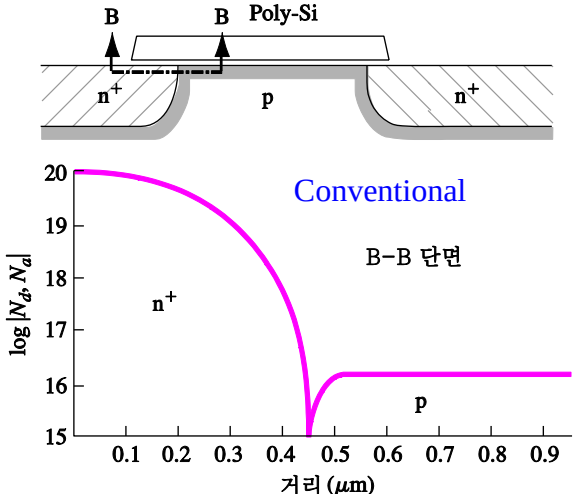
DIBL : In short channel MOSFET, large drain voltage reduces the barrier height in the source side.

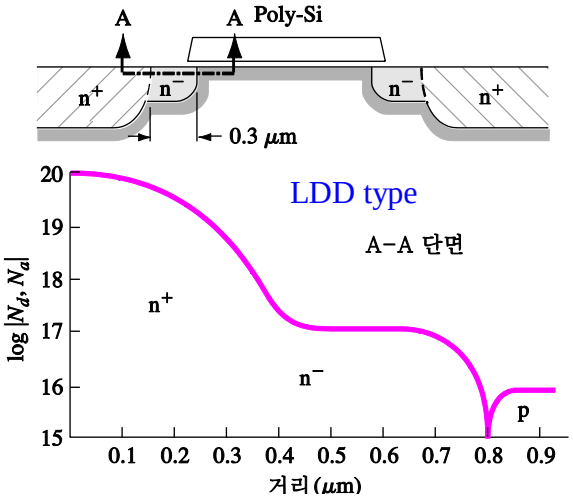


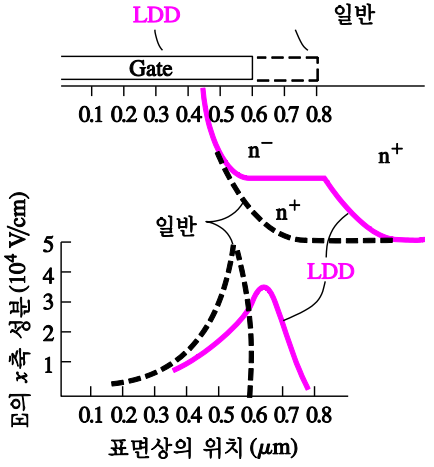




Lightly-Doped-Drain (LDD) Structure : reduce the peak electric field in depletion region



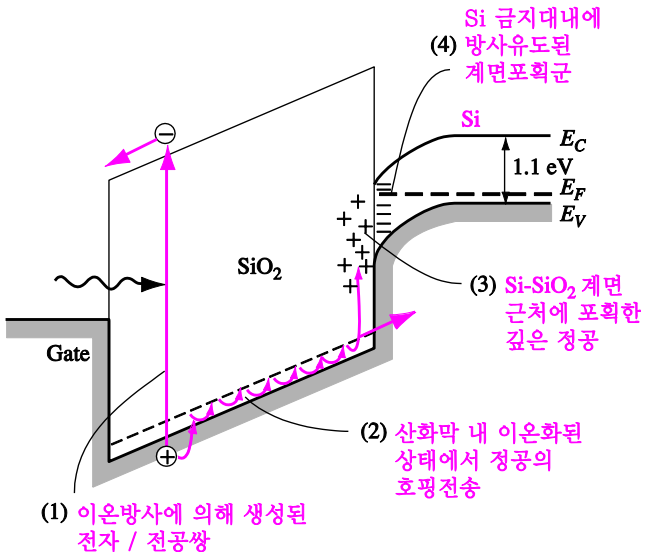


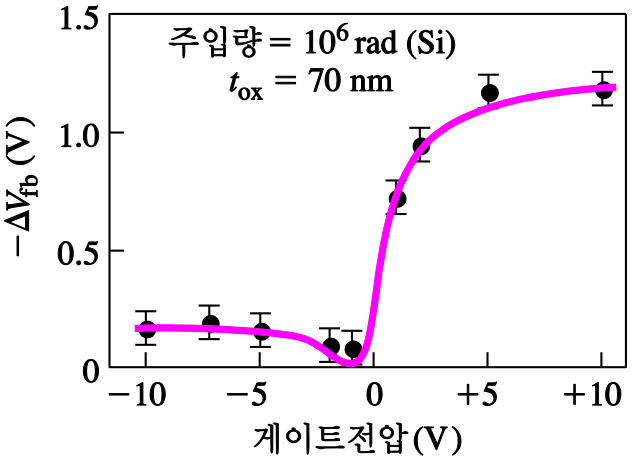


Ionized Radiation and Hot-electron Effects

Ionized radiation can produce additional fixed oxide charge and also additional interface states.

→Makes reliability-related issues.





Radiation-induced V_{FB} shifts

Hot electron : the generated high energy electrons in drain-side depletion region at high VDS

→Can tunnel into oxide or further into gate

→Negative local oxide charge and gate current

→Continuous process and degrade the reliability of devices.