Chapter 18.

NONIDEAL MOS

Sung June Kim

kimsj@snu.ac.kr

http://helios.snu.ac.kr

CONTENTS

Physics of Non-ideal MOS-C

//

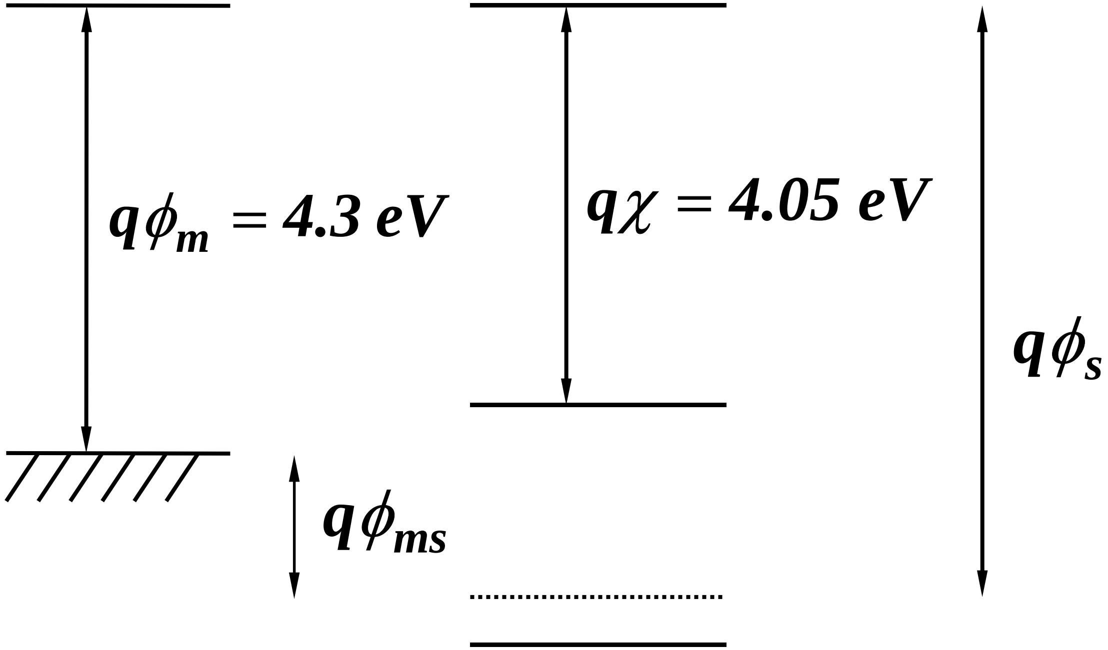
“ real ”

① $\phi_{ms} \neq 0$

② charges exist in SiO_2

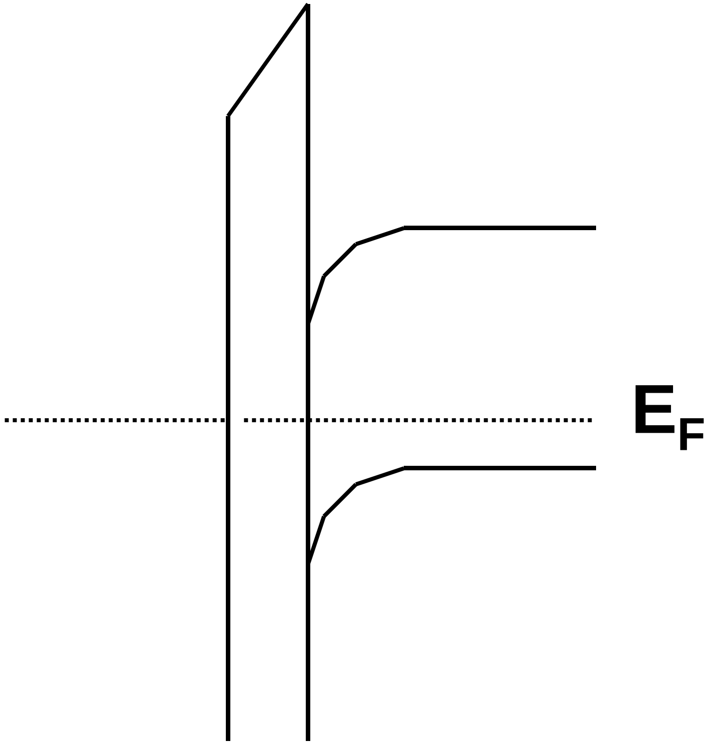
Workfunction Difference

- Workfunction :
  - the minimum energy required to bring an electron from the Fermi level to the vacuum level.
  - for $A\ell$, $q\phi_m = 4.3\ e\mathrm{V}$.
- Electron affinity :
  - the energy difference between conduction band edges of the semiconductor and the vacuum level.
  - for silicon, $q\chi = 4.05\ e\mathrm{V}$.



Al

Silicon

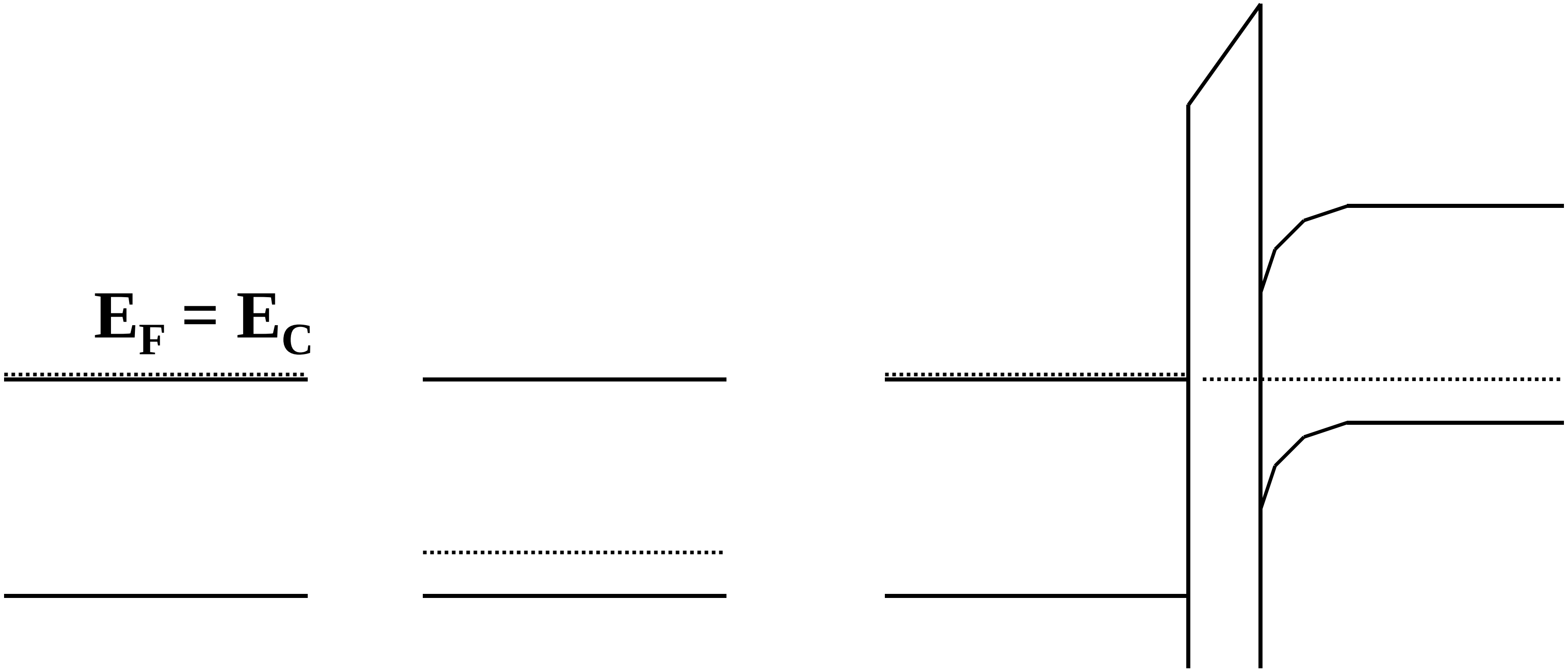


Equilibrium

$$\phi_m \neq \phi_s$$

$$V_{FB} = \phi_{ms}$$

Heavily-doped polysilicon gate



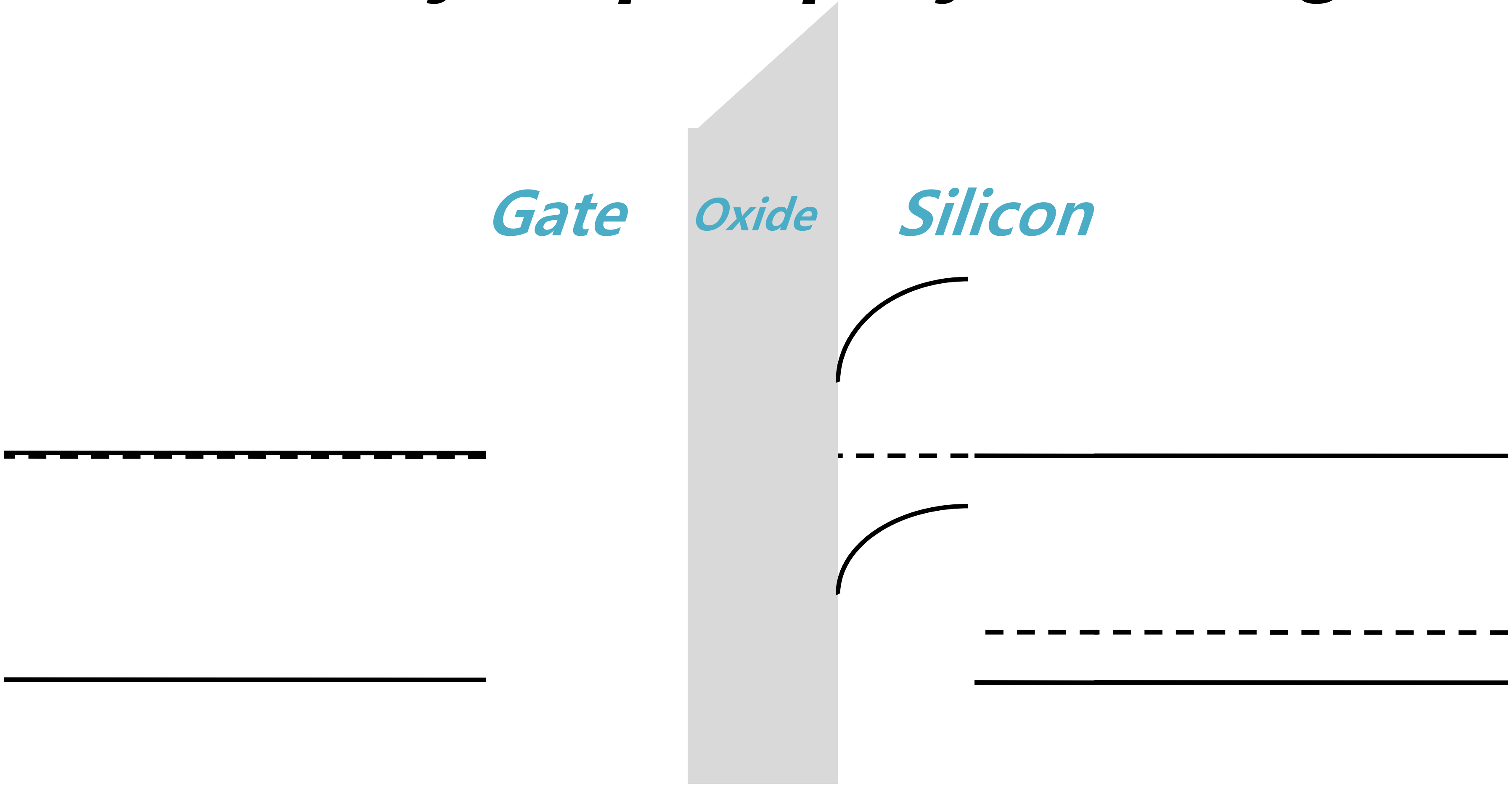
$E_F = E_C$

gate

bulk

at equilibrium

Heavily-doped polysilicon gate



$$\phi_{ms} = -E_g/2 - \phi_F$$

$$= -E_g/2 - \frac{kT}{q}\ln\left(\frac{N_A}{n_i}\right)$$

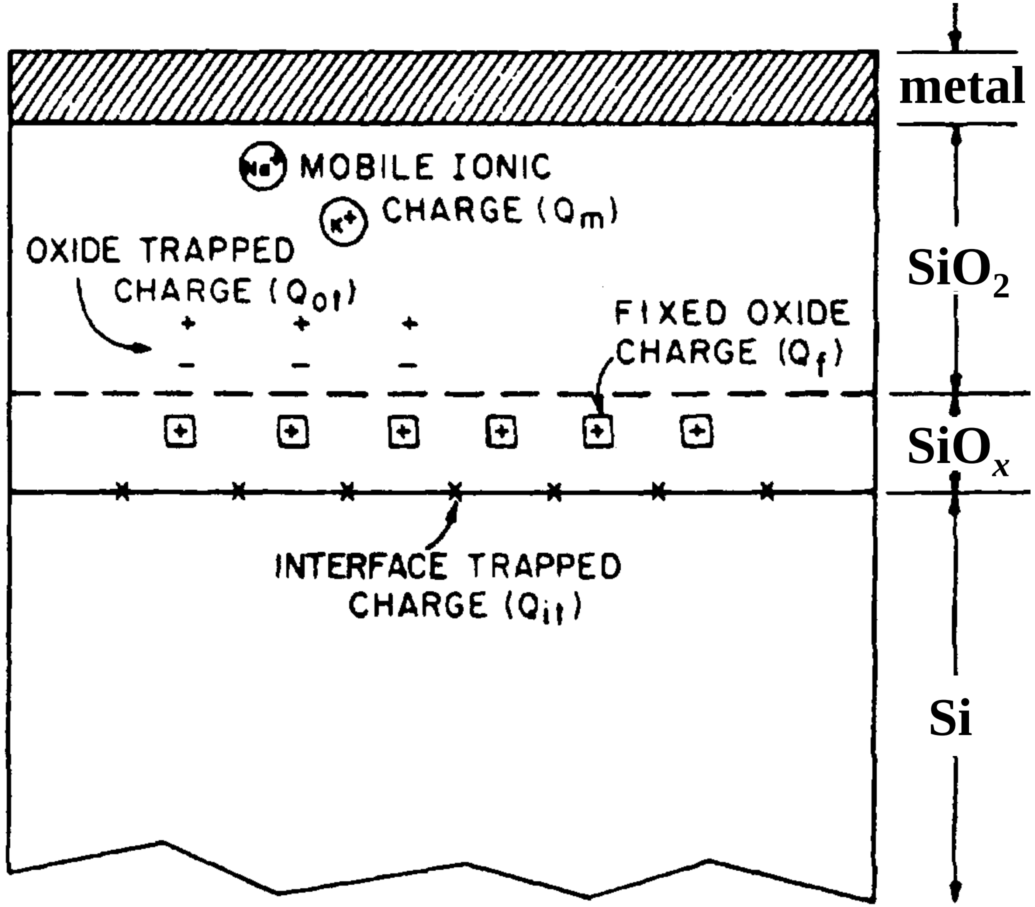
약 -900 mV

~ 560mV

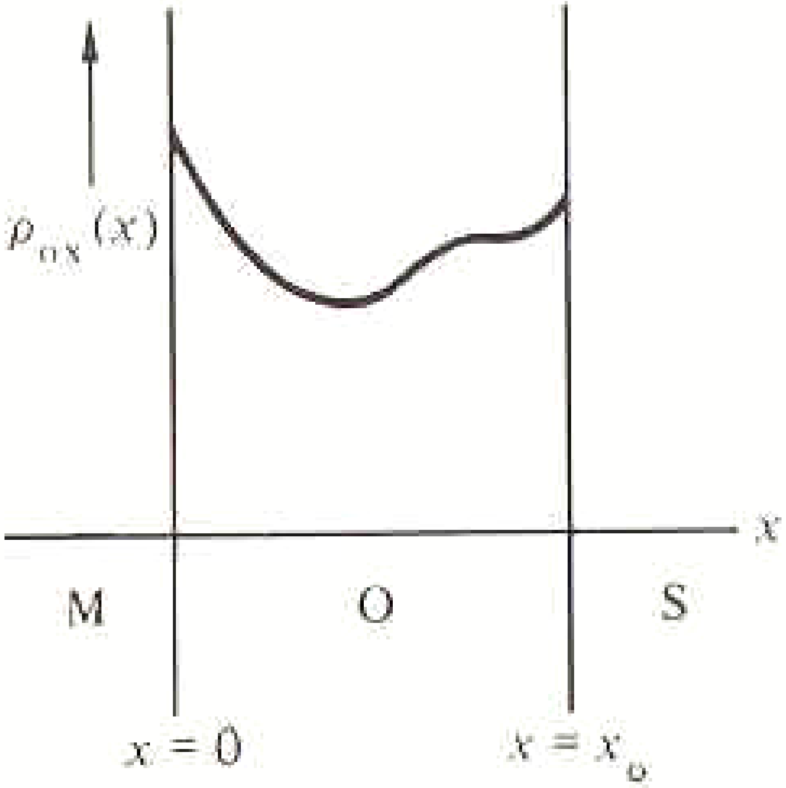
~ 350mV

Oxide Charges and Traps

- Q_{tot} : total oxide charges (per unit area)



NONIDEAL MOS

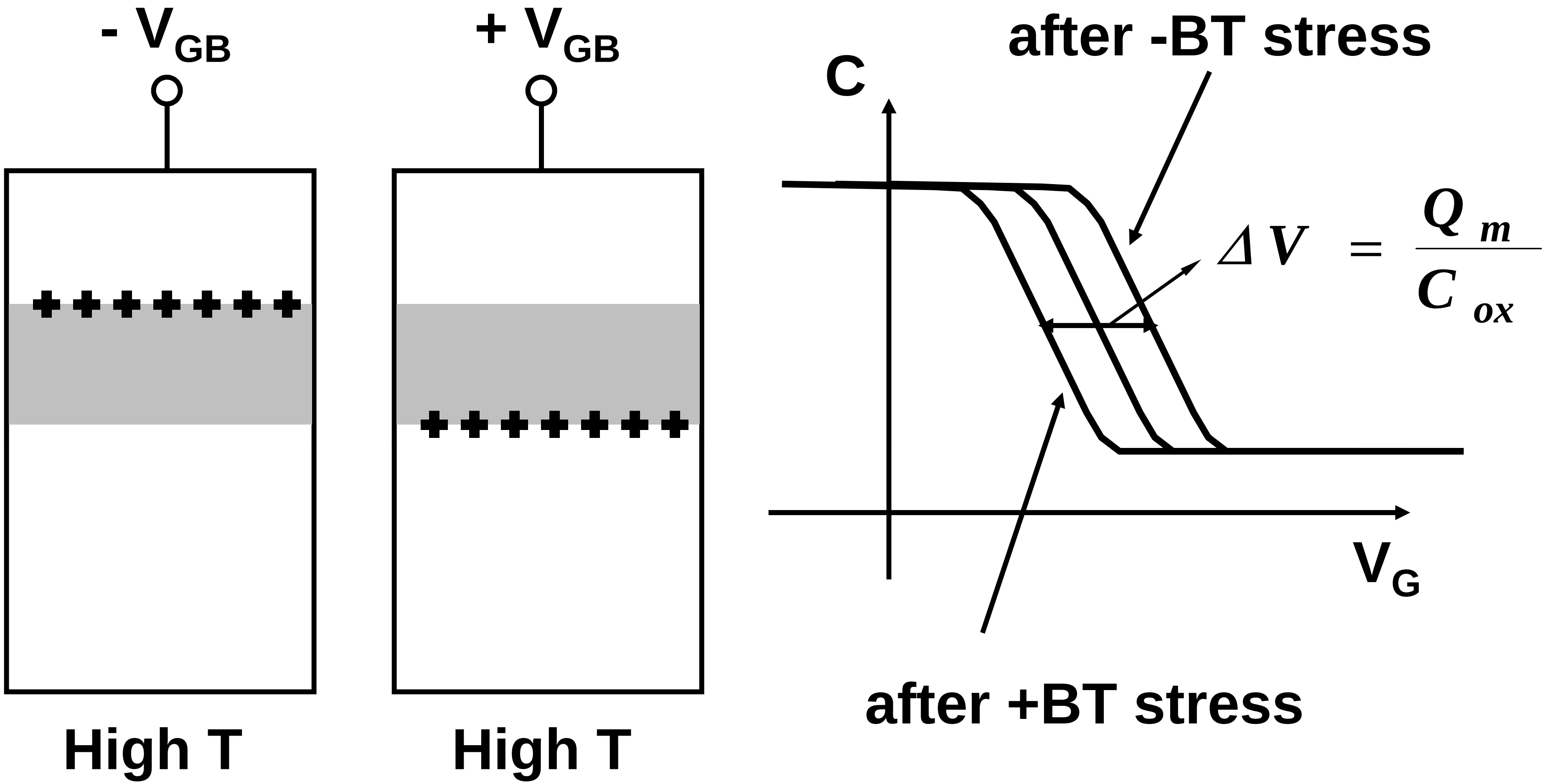


$$\Delta V_T = -\frac{1}{K_o \varepsilon_o} \int_0^{x_o} x\, \rho_{ox}(x)\, dx$$

Mobile Ionic Charges

- Na^+, K^+
- Very high diffusivities in the oxide even below 200 °C
  - V_T instability

- Test : MOS-C CV



$$\Delta V = \frac{Q_m}{C_{ox}}$$

Fixed Oxide Charge

1. Located very close to the interface
2. Associated with the structure of the interfacial between Si and SiO_2
3. Function of substrate orientation, oxidation temperature (anneal condition)

(111) > (110) > (100)

↑

$1\times10^{10}\ \text{cm}^{-2}$ $\therefore$ **(100) wafers are used for MOS IC**

$$\Delta V_T = \frac{-Q_f}{C_{ox}} = \frac{-qN_f}{C_{ox}}$$

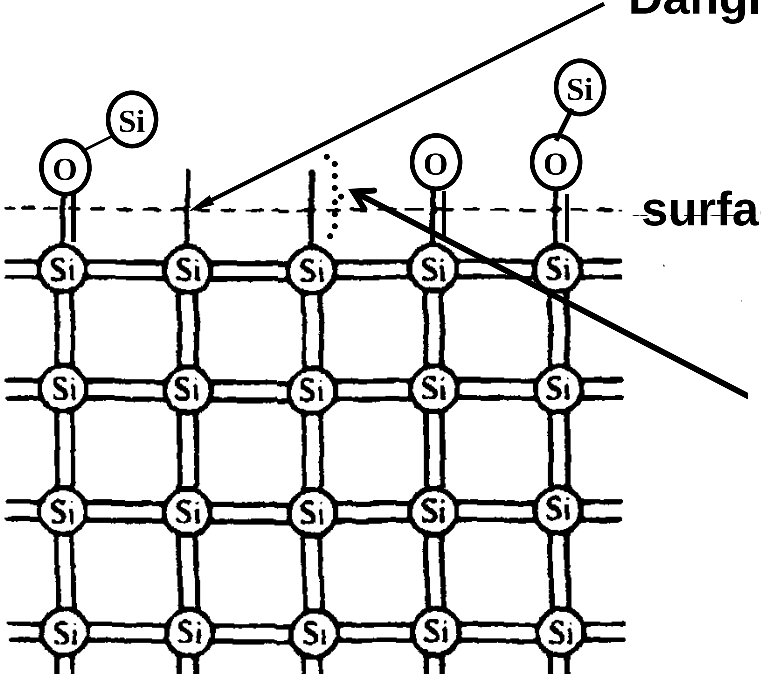
$$(100)\quad t_{ox} = 50\text{Å},\quad C_{ox} = \frac{K_{ox}\varepsilon_o}{t_{ox}} = \frac{3.9\times 8.854\times 10^{-14}\,\text{F/cm}}{50\times 10^{-8}\,\text{cm}} = 690\ \text{nF/cm}^2$$

$$\Delta V_T = -\frac{\left(1.6\times 10^{-19}\ C\right)\left(1\times 10^{10}\ cm^{-2}\right)}{690\times 10^{-9}\ F/cm^2} = 2.5\ \text{mV}$$

Interface Trapped Charge

1. Arises from allowed energy states in the forbidden gap of the Si, very close to Si-SiO_2 interface.
2. Physical origin unknown yet.

   → "dangling bond" (?)



Dangling bond

surface

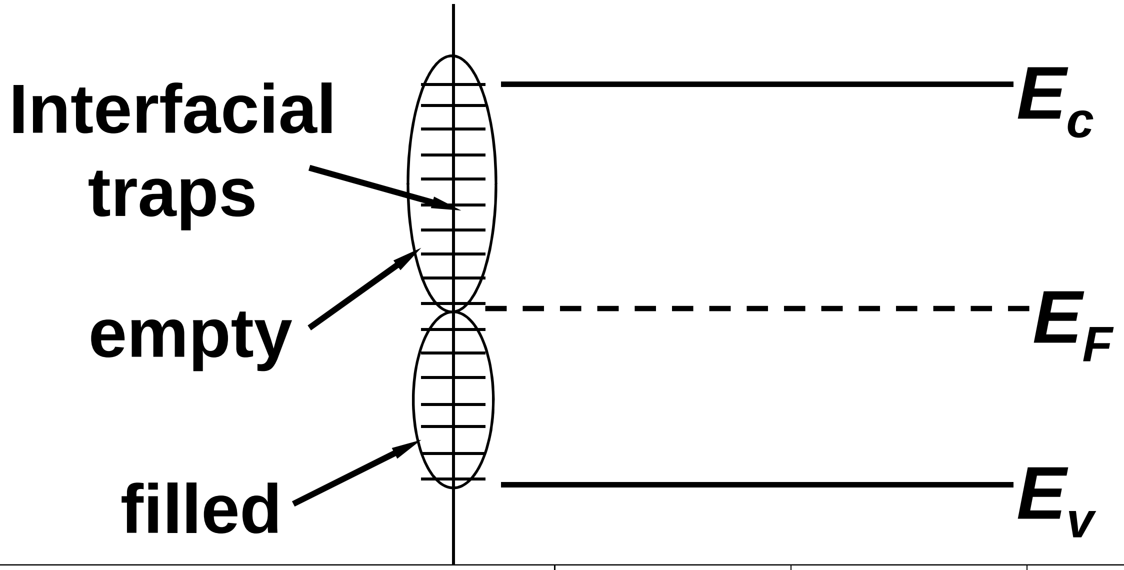
electron can be trapped

NONIDEAL MOS

3. The surface state acts like a recombination center.

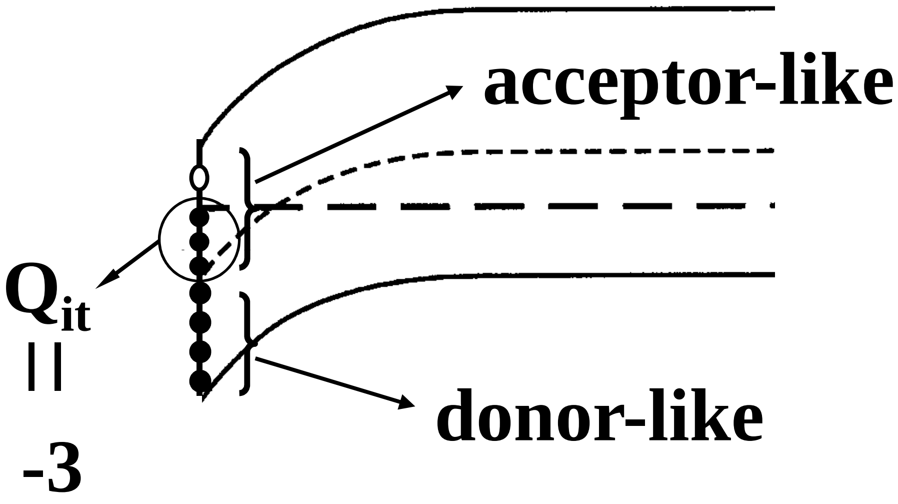
4. Function of V_{GB} → 가장 나쁜 charge.

5. Distributed throughout the entire band gap

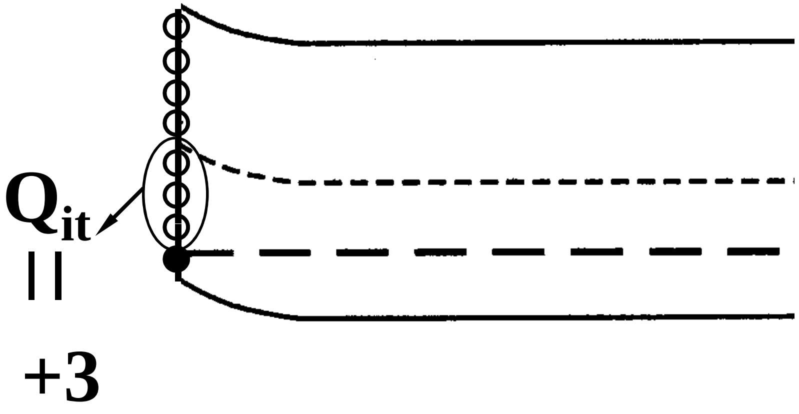


	Filled	Empty	
donor-like traps	“0”	“+”	below E_i
acceptor-like traps	“-”	“0”	above E_i

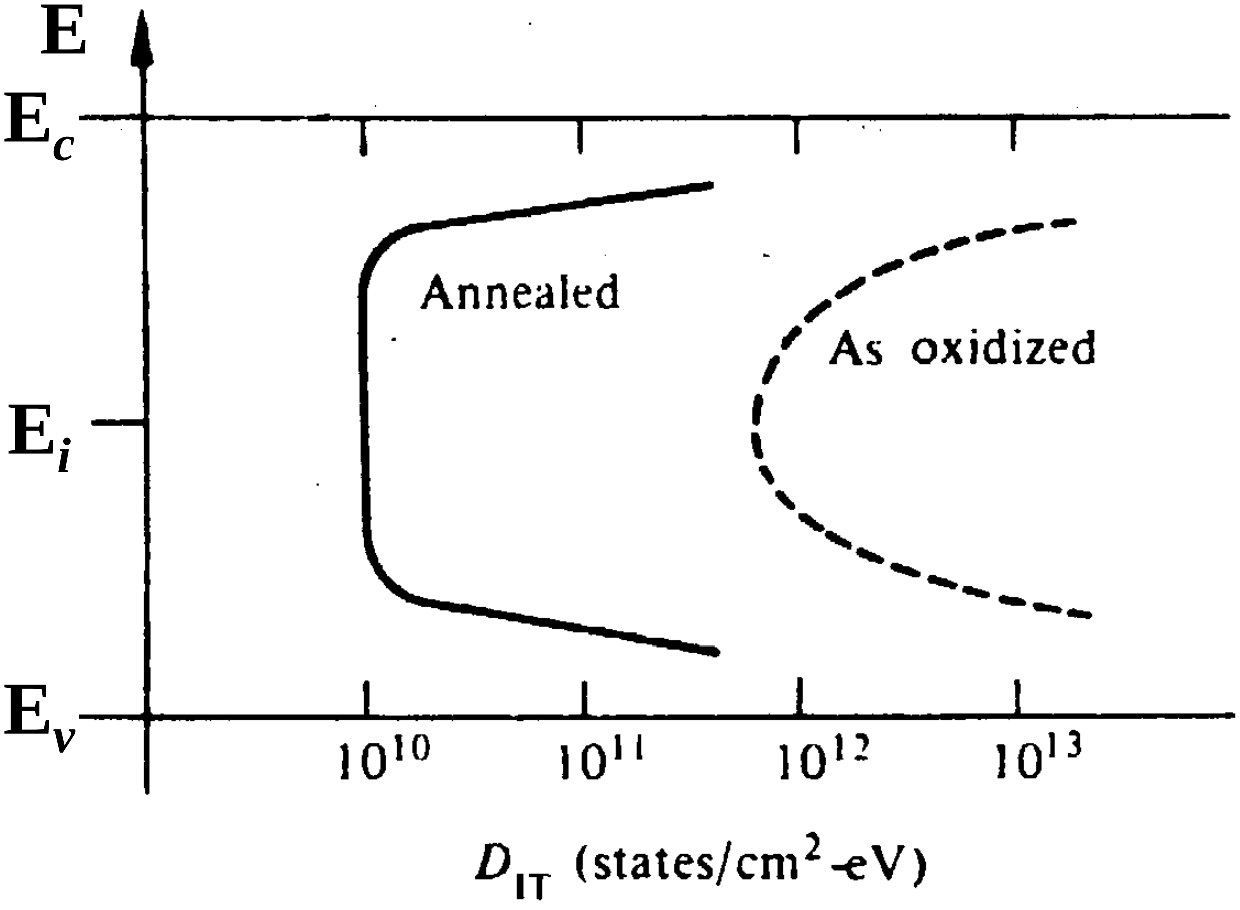
- inversion :
  mostly filled



- accumulation :
  mostly empty



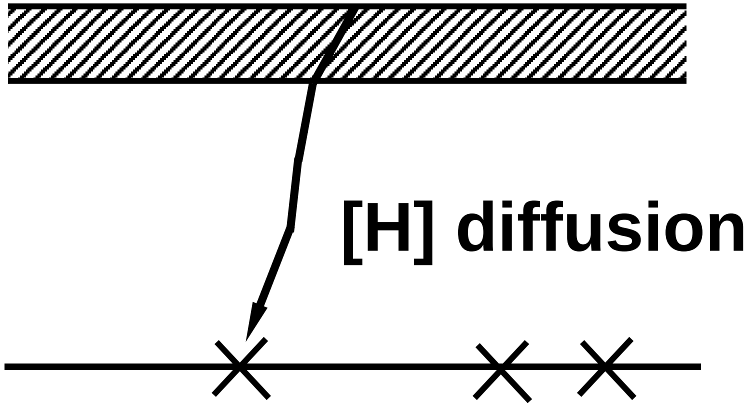
6. Distribution of trap level vs. energy



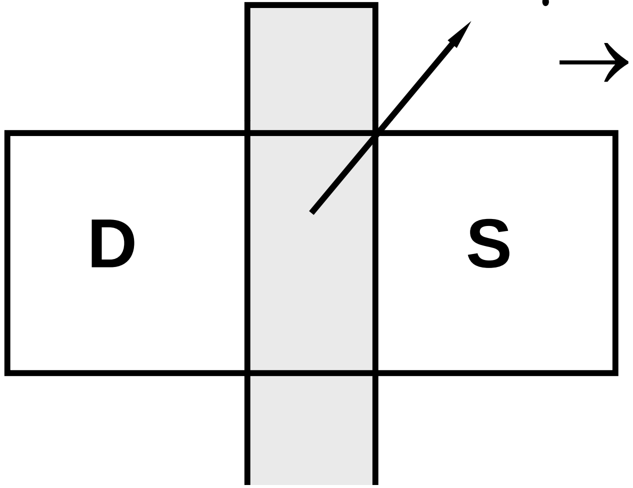
N_{it} (#/cm^2)

7. (111

8. Annealing with hydrogen at relatively low temperature (≤ 500 °C) minimize D_{it}.



10^{10} traps/cm^2 → 100 traps/μm^2



0.1 μm × 0.1 μm → 1 trap

Oxide Trapped Charge Q_{ot}

- Due to holes and electrons trapped in the bulk of oxide.

Effect of Oxide Charge on V_T

$$\Delta V_T = -\frac{Q_{tot}}{C_{ox}}$$ **(If Q_{tot} at the interface)**

Threshold Voltage Equation

- Flat band voltage $\equiv V_{FB} \equiv \phi_{ms} - \dfrac{Q_{tot}}{C_{ox}}$

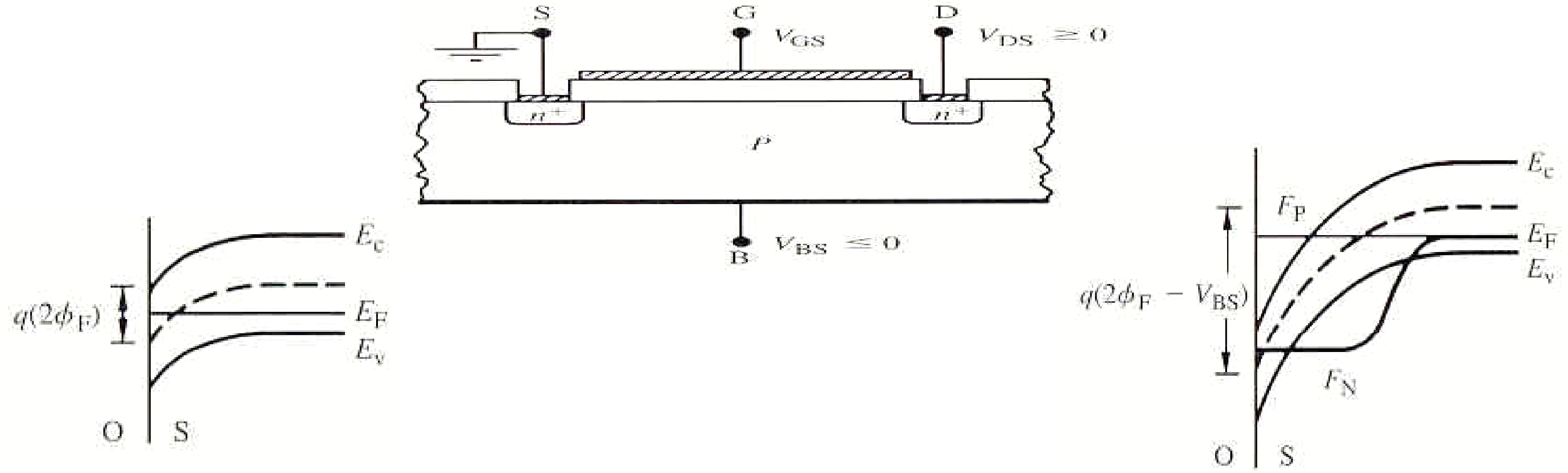
$$V_T = V_{FB} + 2\phi_F + \frac{\sqrt{4K_s\,\varepsilon_0\,q\,N_A\,\phi_F}}{C_{ox}} \qquad \sim 0.6\ \text{V}$$

potential drop in Si

potential drop in oxide

Back Biasing

- Body effect: Reverse biasing the back contact relative to the source → V_T change



If V_{BS}=0, inversion occurs when $\phi_s=2\phi_F$

If V_{BS}<0, inversion layer carriers migrate laterally into the S/D. The inversion occurs when $\phi_s=2\phi_F+|V_{BS}|$. The maximum depletion width

$$W_T = \sqrt{\frac{2K_s\varepsilon_o\left(2\phi_F + |V_{BS}|\right)}{qN_A}}$$

- At threshold,

$$V_{GB} = V_{FB} + 2\phi_F + |V_{BS}| + \frac{\sqrt{2qK_s\varepsilon_o N_A\left(2\phi_F + |V_{BS}|\right)}}{C_{ox}}$$

$$\therefore \underset{\displaystyle V_T}{\underset{\parallel}{V_{GS}}} = V_{GB} + V_{BS} = V_{FB} + 2\phi_F + \frac{\sqrt{2qK_s\varepsilon_o N_A\left(2\phi_F + |V_{BS}|\right)}}{C_{ox}}$$

$$= V_T(V_{BS} = 0) + \underbrace{\frac{\sqrt{2qK_s\varepsilon_o N_A}}{C_{ox}}}_{\textbf{Body Factor}}\left(\sqrt{2\phi_F + |V_{BS}|} - \sqrt{2\phi_F}\right)$$