MOS

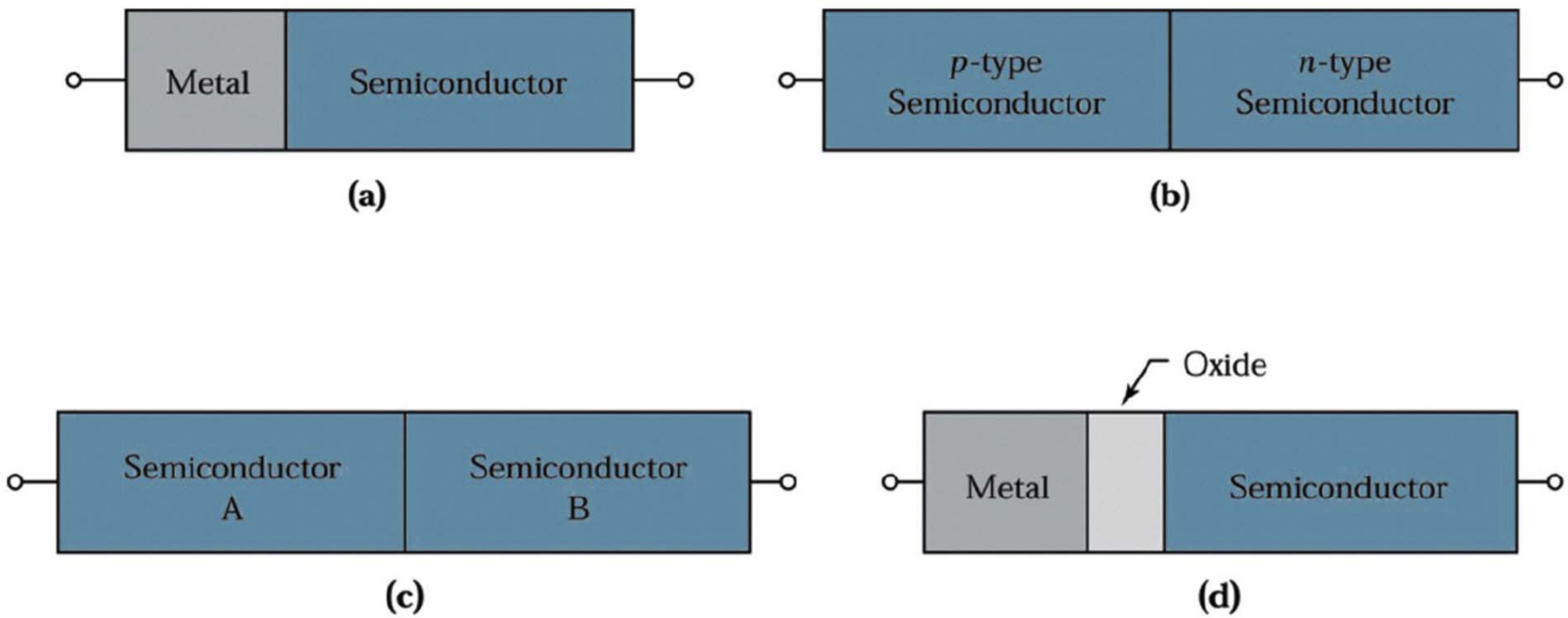
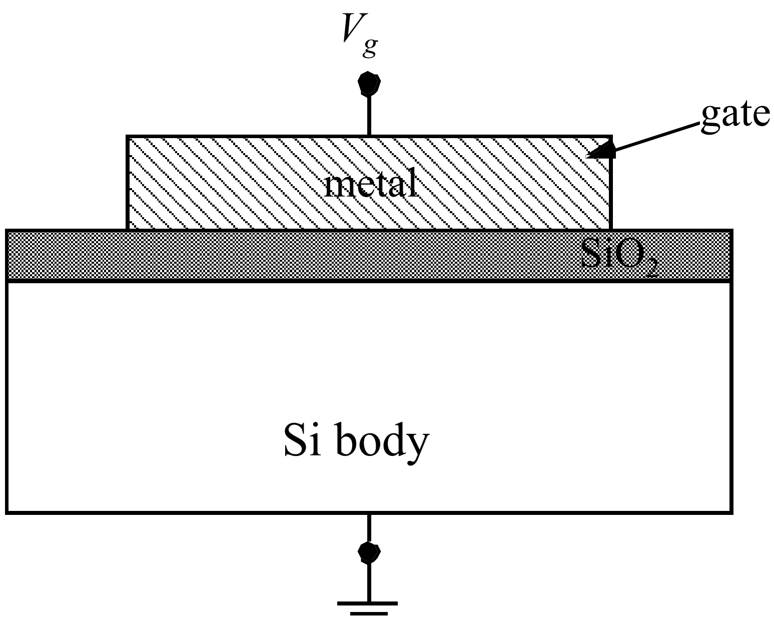


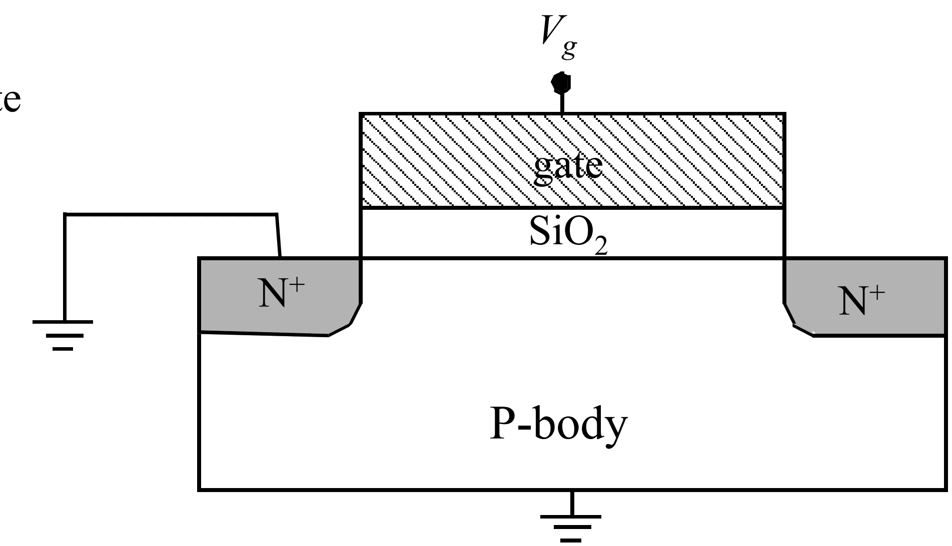
Figure 0.2

Basic device building blocks. (*a*) Metal-semiconductor interface; (*b*) *p*-*n* junction; (*c*) heterojunction interface; and (*d*) metal-oxide-semiconductor structure.

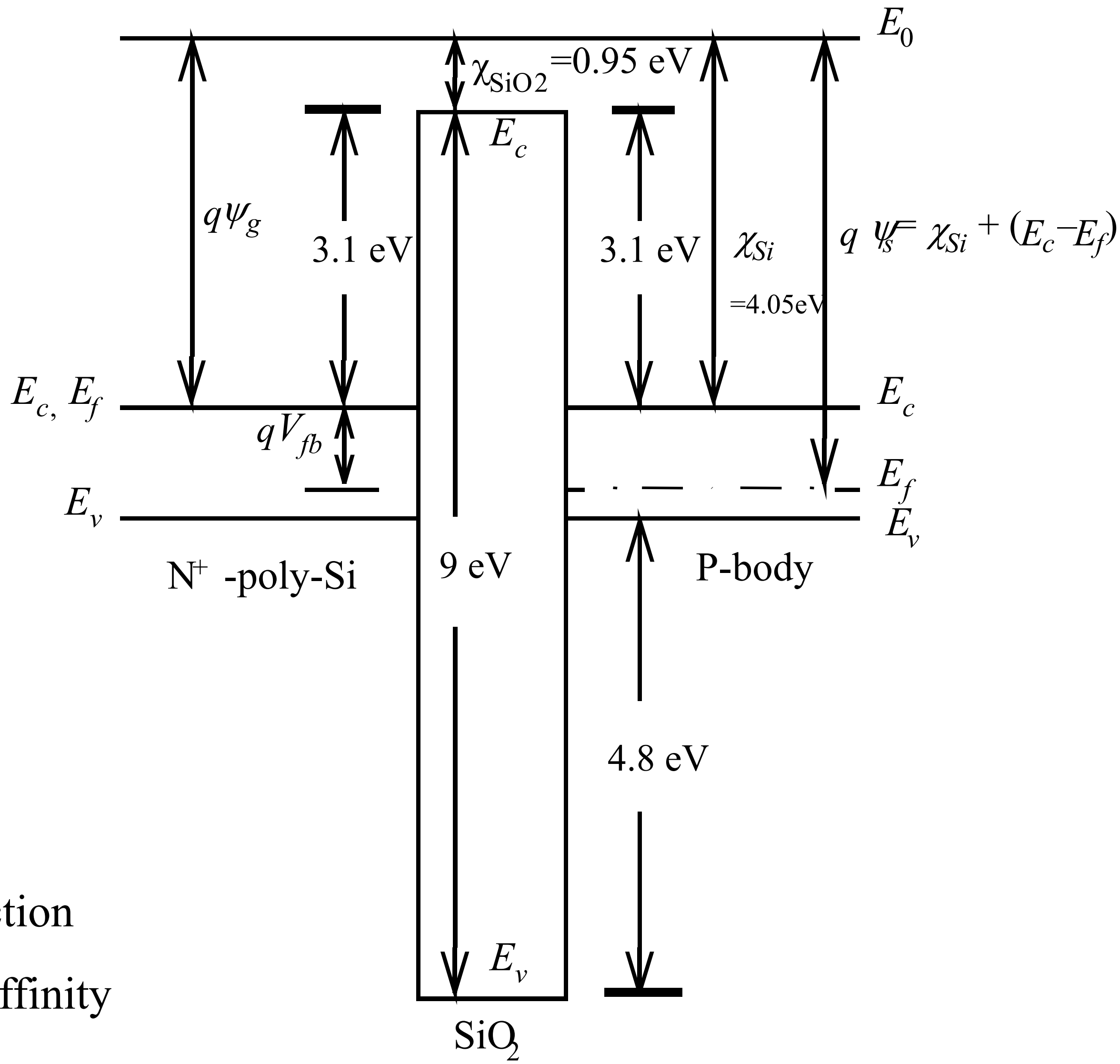
MOS: Metal-Oxide-Semiconductor



MOS capacitor



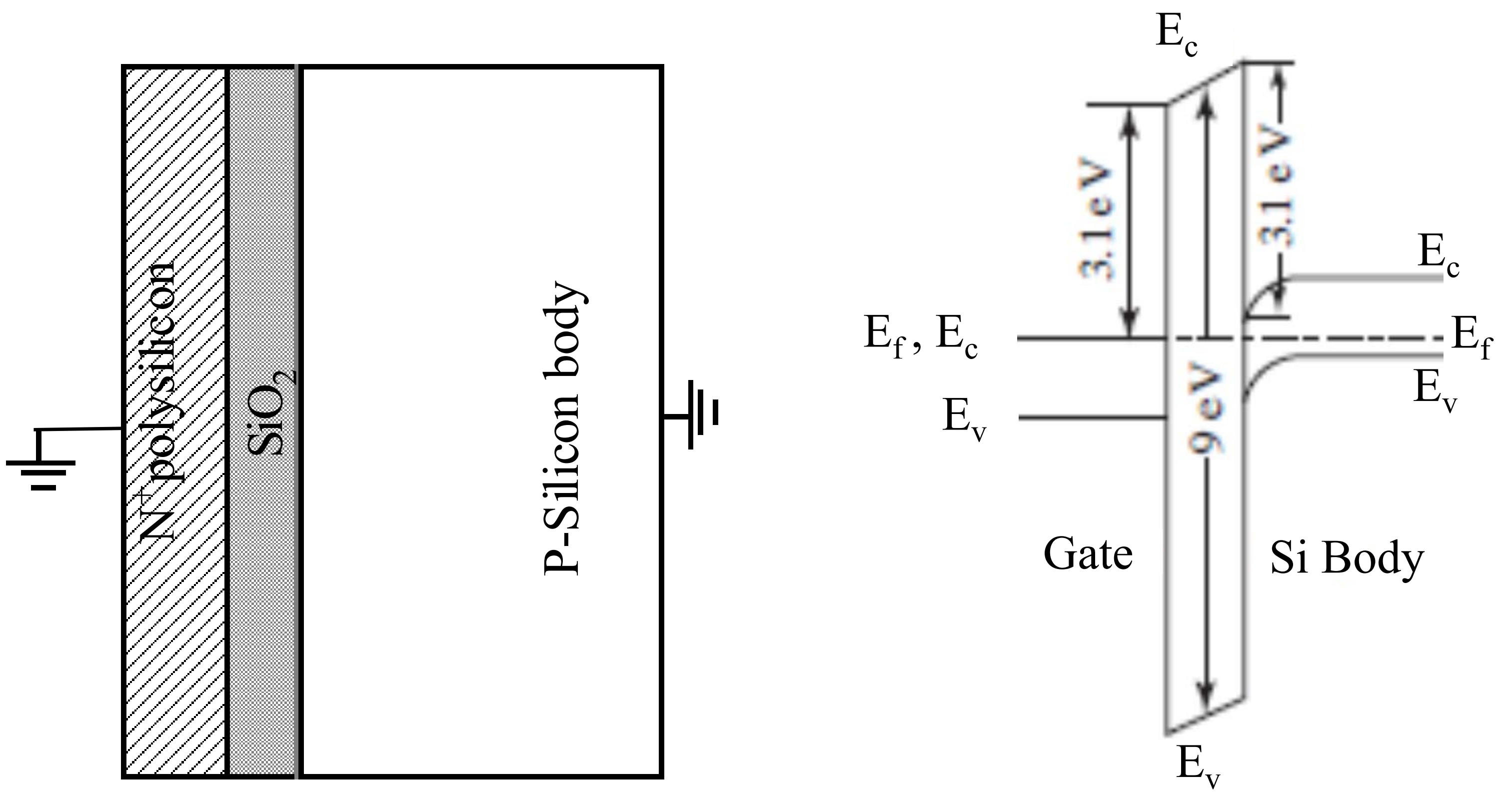
MOS transistor



E_0 : Vacuum level

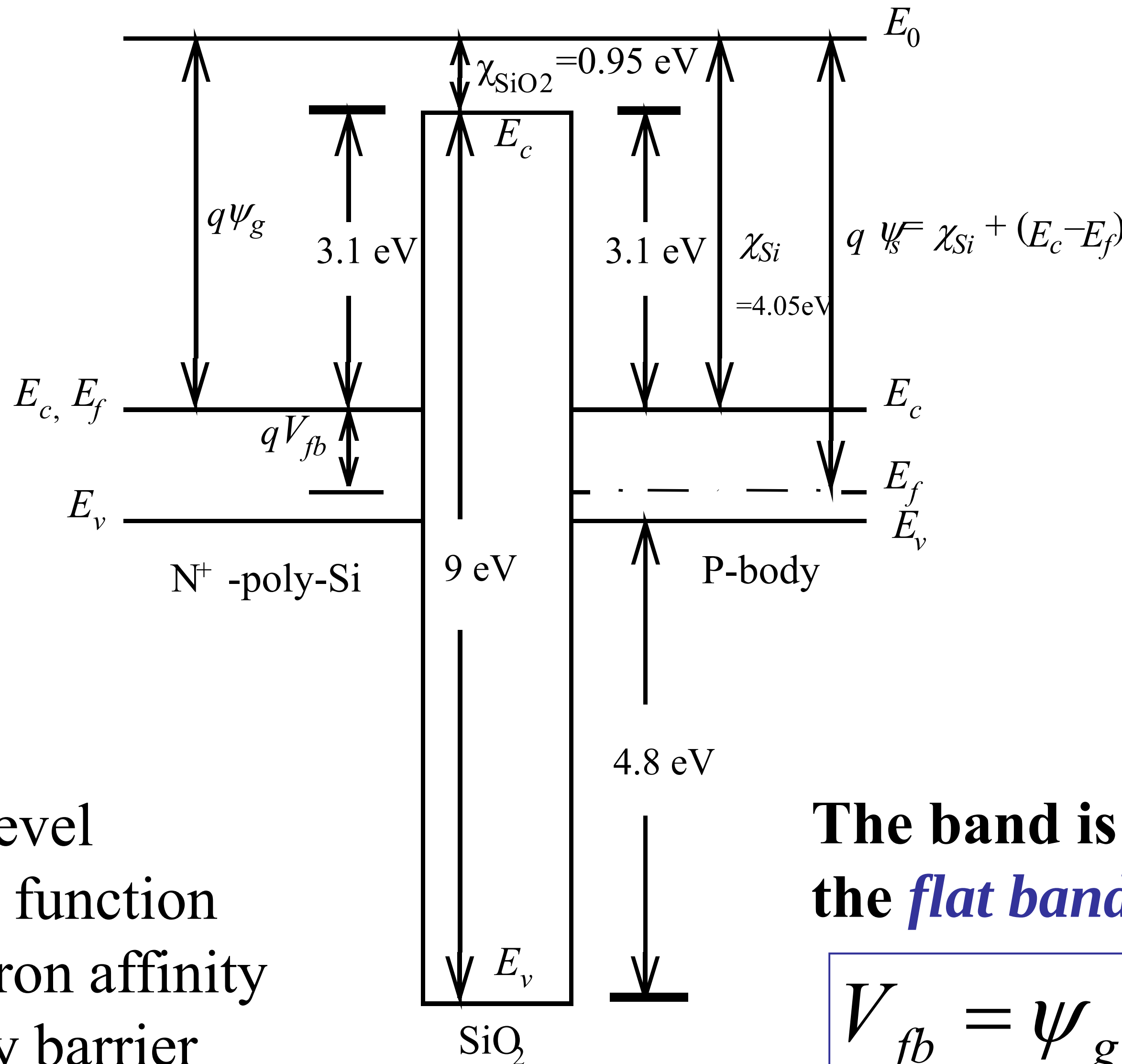
$E_0 - E_f$: Work function

$E_0 - E_c$: Electron affinity



Energy-band diagram for $V_g = 0$

Flat-band Condition and Flat-band Voltage

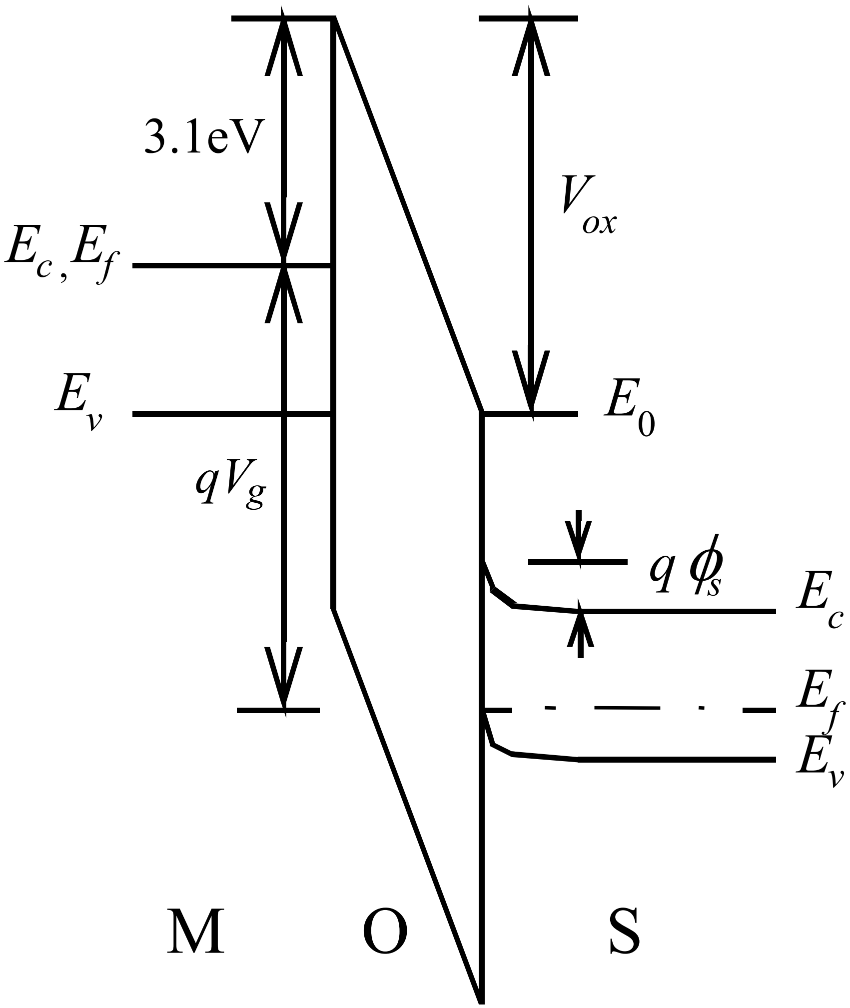


E_0 : Vacuum level
$E_0 - E_f$: Work function
$E_0 - E_c$: Electron affinity
Si/SiO_2 energy barrier

The band is flat at the *flat band voltage*.

$$\boxed{V_{fb} = \psi_g - \psi_s}$$

Surface Accumulation



Make $V_g < V_{fb}$

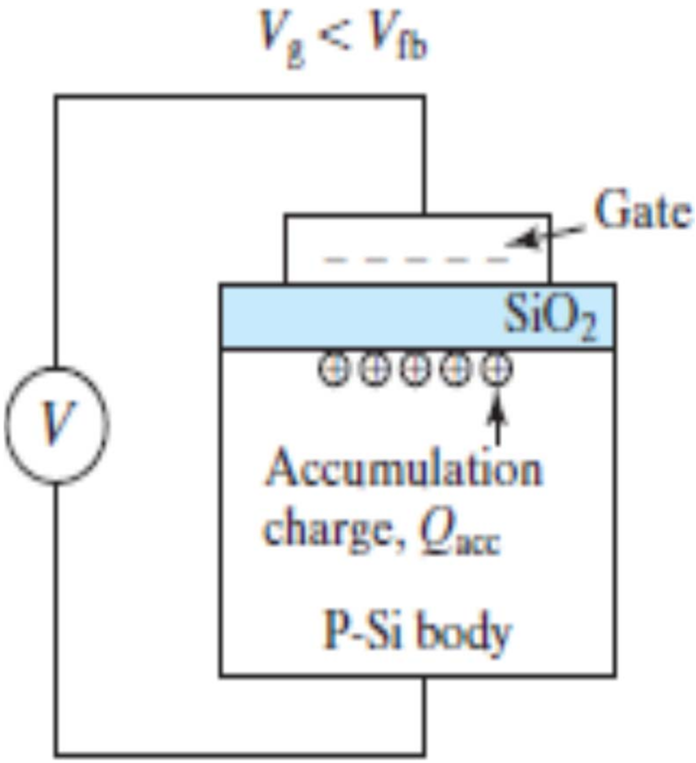
$$\boxed{V_g = V_{fb} + \phi_s + V_{ox}}$$

ϕ_s : surface potential, band bending

V_{ox}: voltage across the oxide

ϕ_s is negligible when the surface is in accumulation.

Surface Accumulation



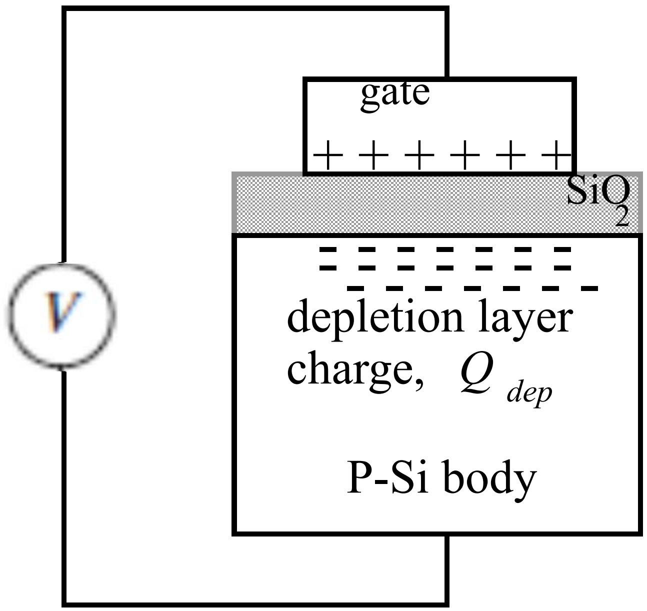
$$V_{ox} = V_g - V_{fb}$$

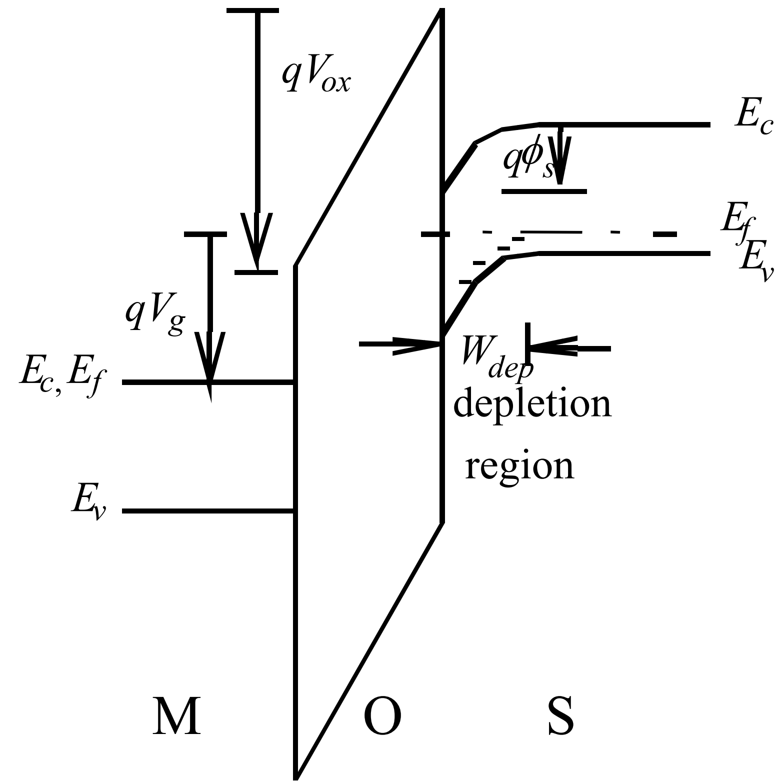
Gauss's Law $\rightarrow V_{ox} = -Q_{acc} / C_{ox}$

$$Q_{acc} = -C_{ox}(V_g - V_{fb})$$

$$\boxed{V_{ox} = -Q_s / C_{ox}}$$

Surface Depletion ($V_g > V_{fb}$)





$$V_{ox} = -\frac{Q_s}{C_{ox}} = -\frac{Q_{dep}}{C_{ox}} = \frac{qN_a W_{dep}}{C_{ox}} = \frac{\sqrt{qN_a 2\varepsilon_s \phi_s}}{C_{ox}}$$

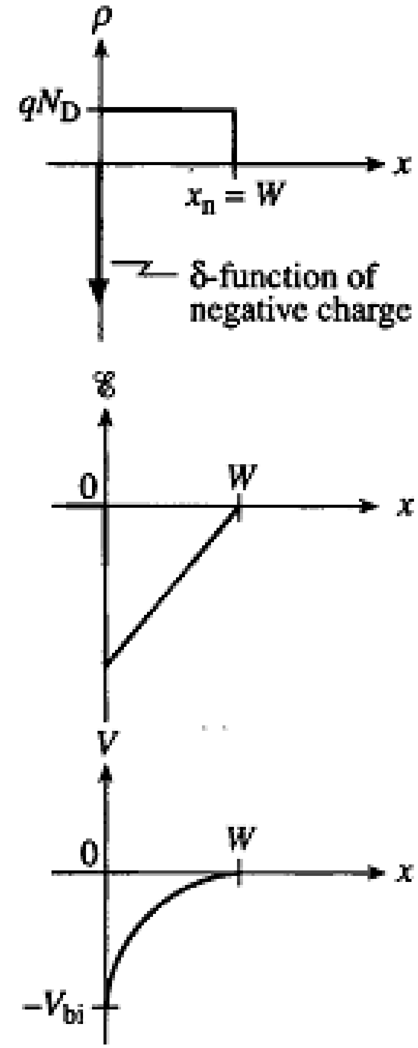
Depletion Width, *W*

$$V(x) = \frac{-qN_D}{2\varepsilon_s}(W-x)^2$$

At $x = 0$, $V = -V_{bi}$

$$\Rightarrow \quad W = \sqrt{\frac{2\varepsilon_s V_{bi}}{qN_D}}$$

• ***W* decreases with increasing N_D**



Surface Depletion

$$V_g = V_{fb} + \phi_s + V_{ox} = V_{fb} + \phi_s + \frac{\sqrt{qN_a 2\varepsilon_s \phi_s}}{C_{ox}}$$

This equation can be solved to yield ϕ_s .

Threshold Condition and Threshold Voltage

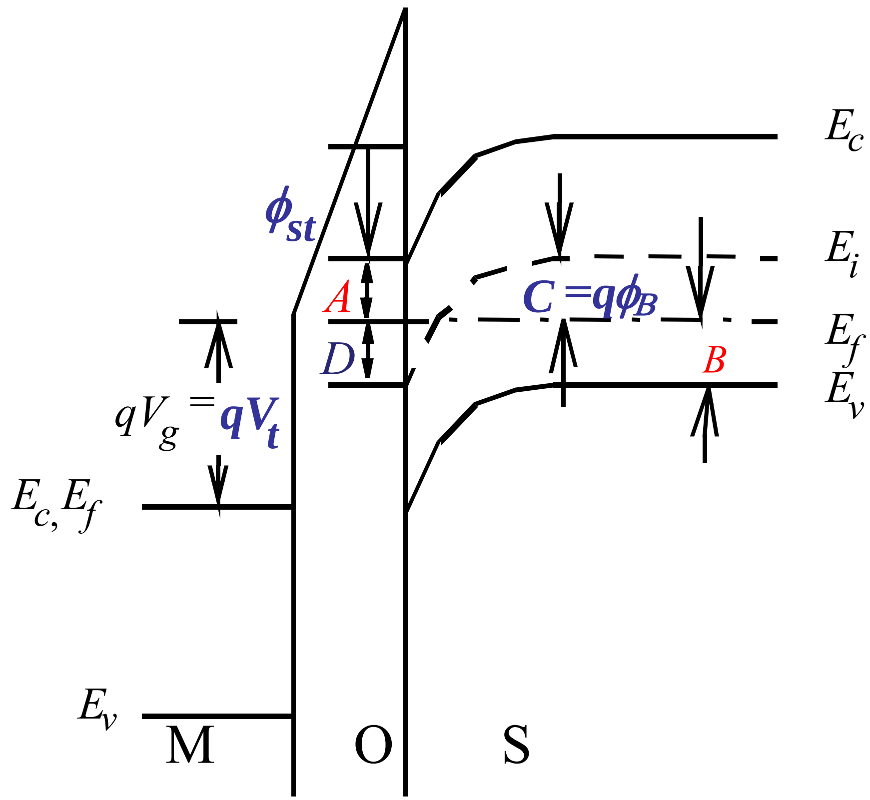
Threshold (of inversion):

$n_s = N_a$, or

$(E_c - E_f)_{surface} = (E_f - E_v)_{bulk}$, or

✧ $A = B$, and $C = D$

$$\boxed{\phi_{st} = 2\phi_B = 2\frac{kT}{q}\ln\left(\frac{N_a}{n_i}\right)}$$



Threshold Voltage

$$V_g = V_{fb} + \varphi_s + V_{ox}$$

At threshold,

$$\varphi_{st} = 2\phi_B = 2\frac{kT}{q}\ln\left(\frac{N_a}{n_i}\right)$$

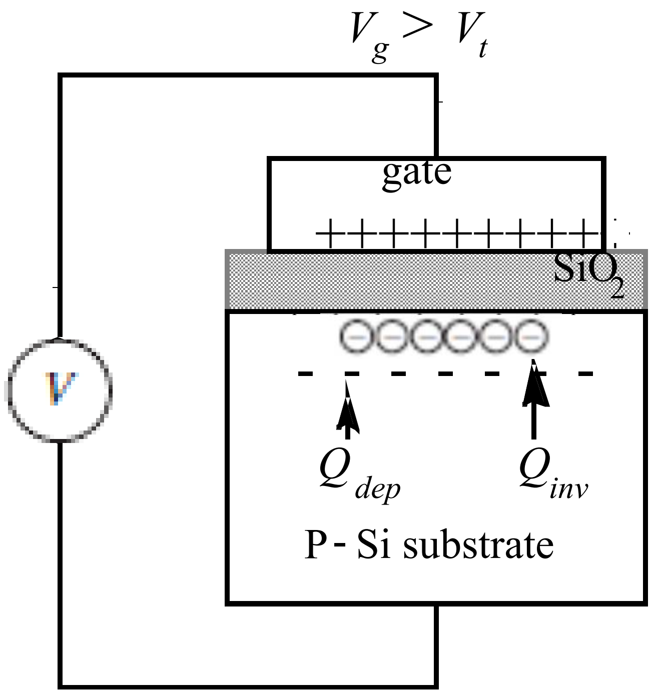
$$V_{ox} = \frac{\sqrt{qN_a 2\varepsilon_s 2\phi_B}}{C_{ox}}$$

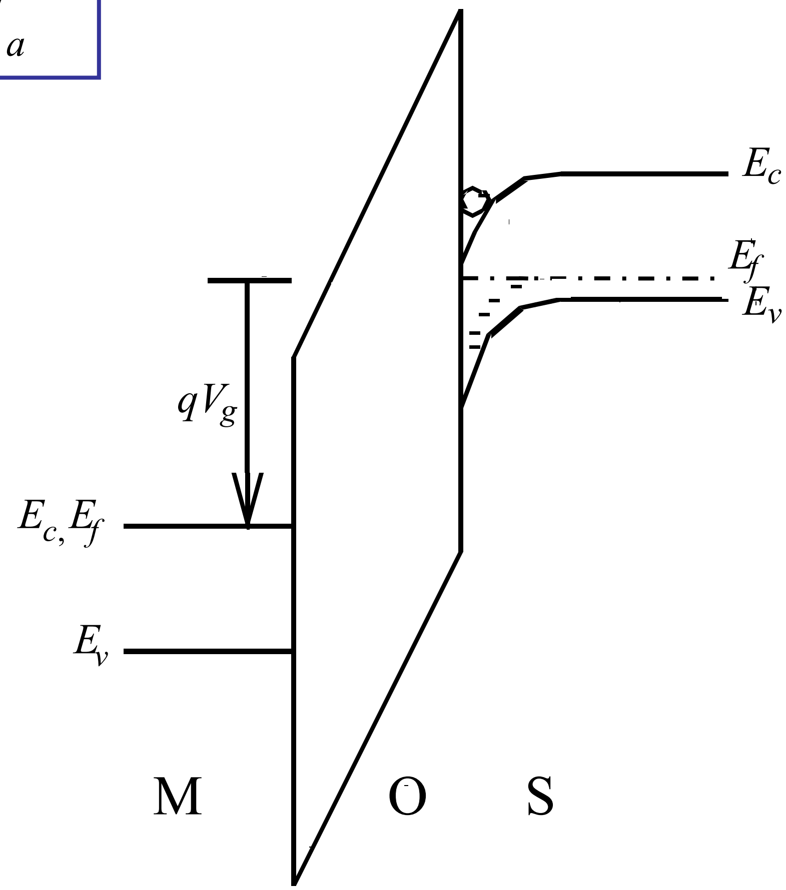
$$\boxed{V_t = V_g \ at\ threshold = V_{fb} + 2\phi_B + \frac{\sqrt{qN_a 2\varepsilon_s 2\phi_B}}{C_{ox}}}$$

Strong Inversion–Beyond Threshold

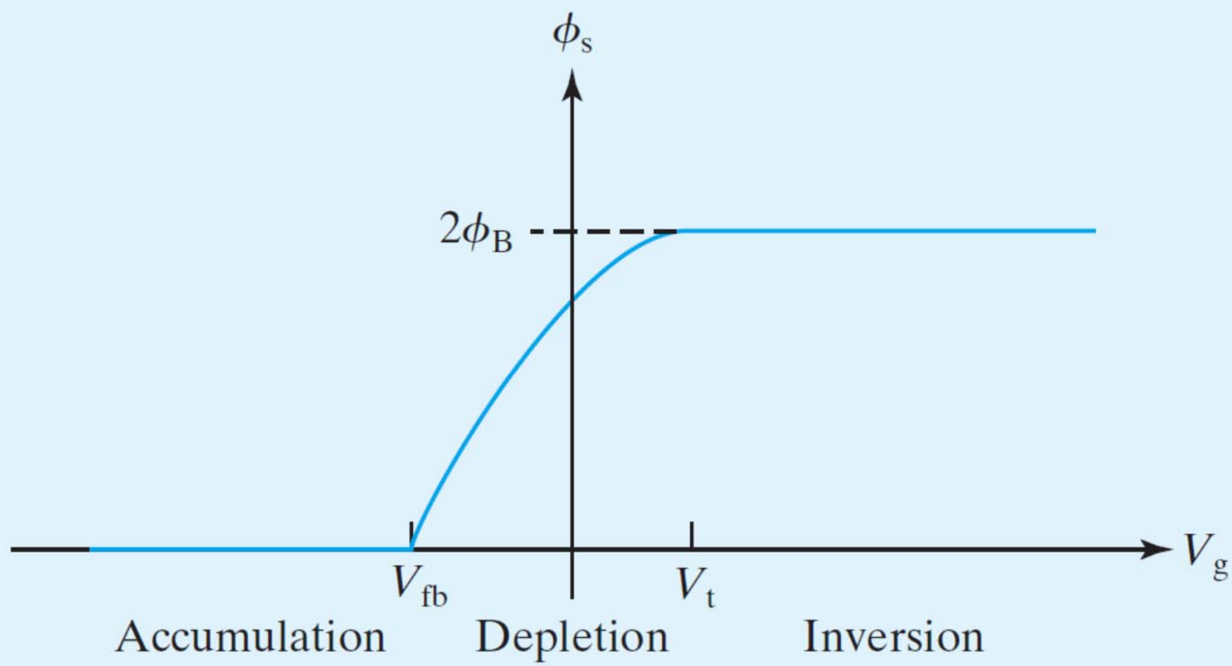
$V_g > V_t$

$$W_{dep} = W_{dmax} = \sqrt{\frac{2\varepsilon_s 2\phi_B}{qN_a}}$$



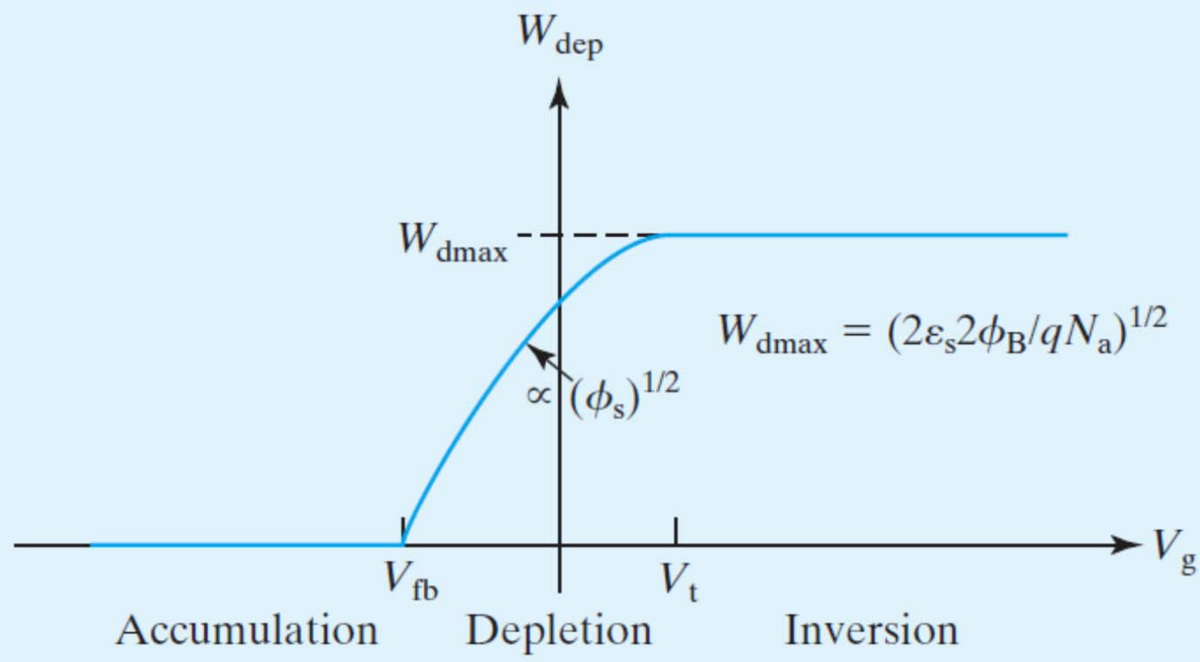


Surface potential vs applied voltage



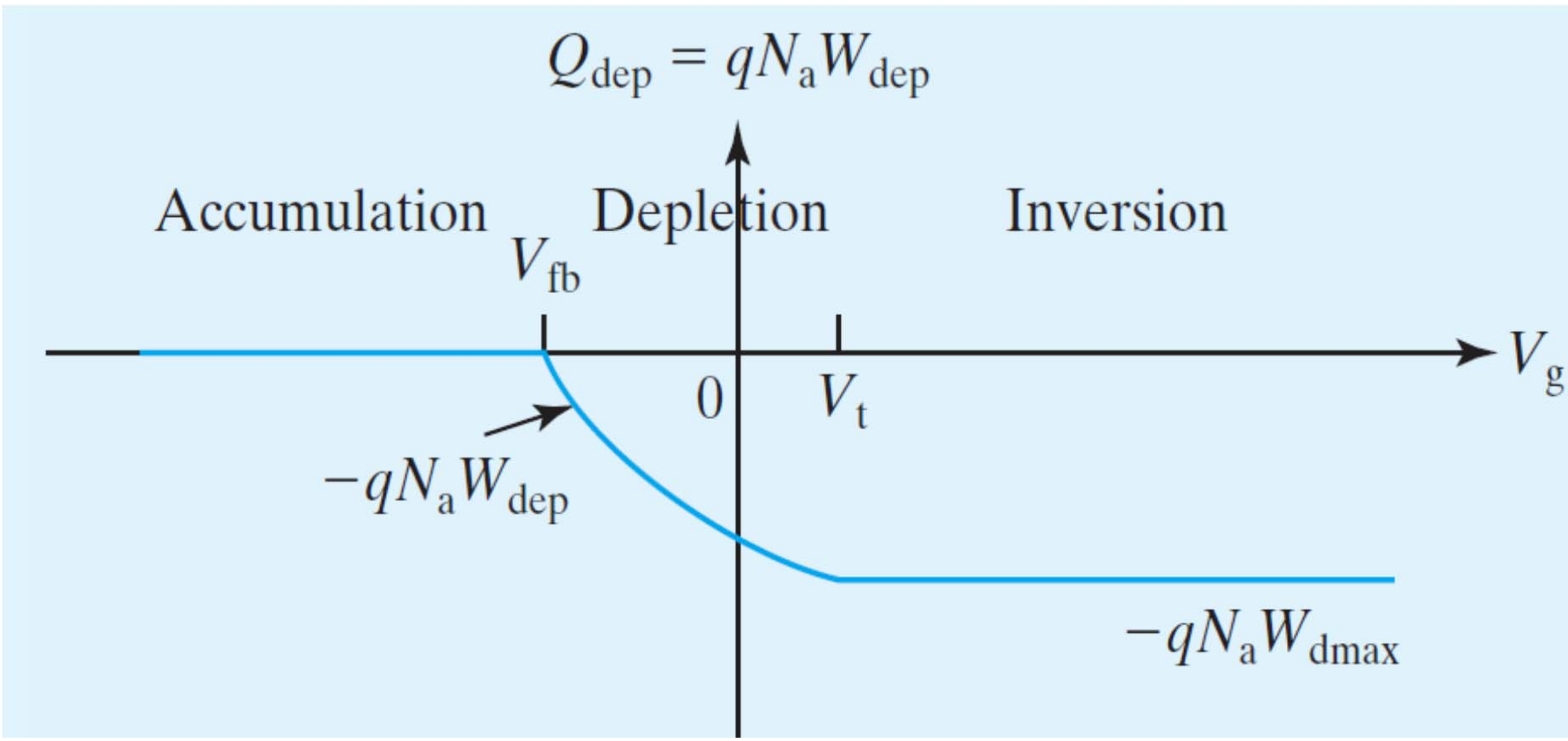
Surface potential saturates at $2\phi_B$ when V_g is larger than V_t.

Depletion width vs applied voltage

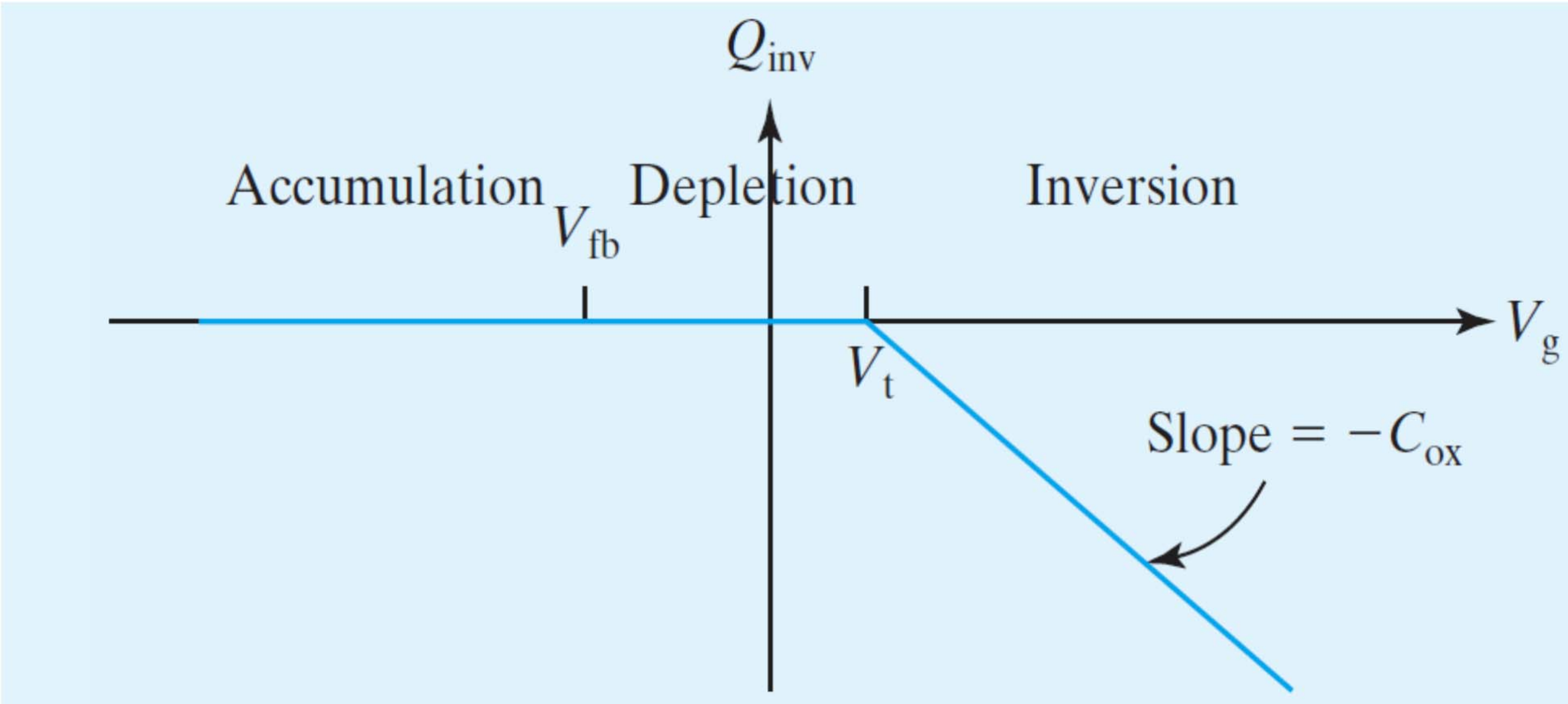


Depletion-region width in the body of an MOS capacitor.

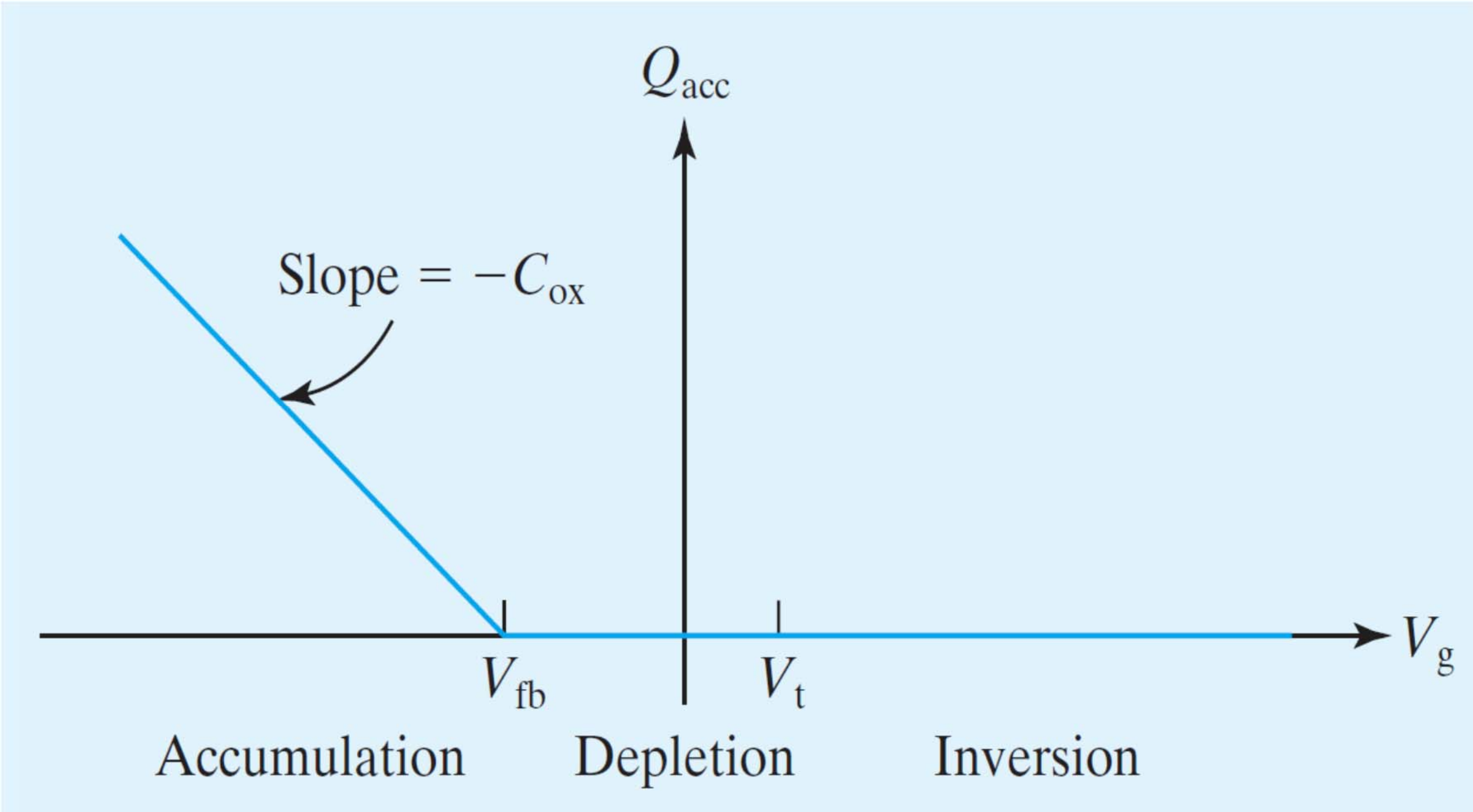
Depletion charge vs applied voltage



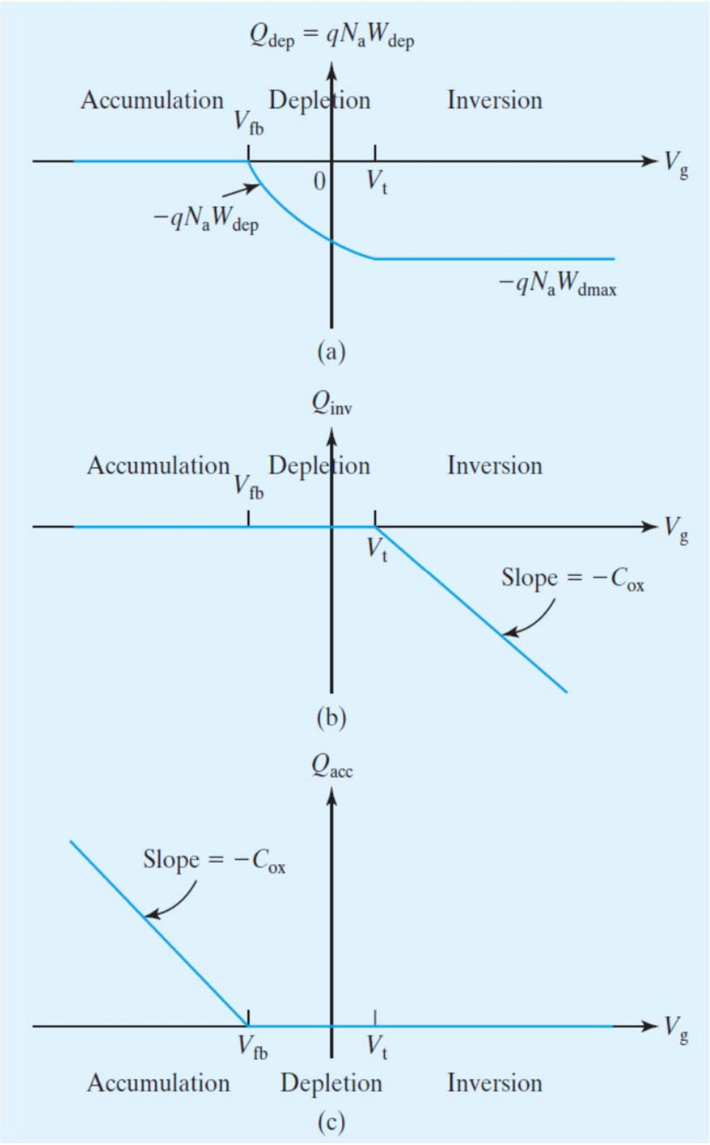
Depletion charge vs applied voltage



Accumulation charge vs applied voltage

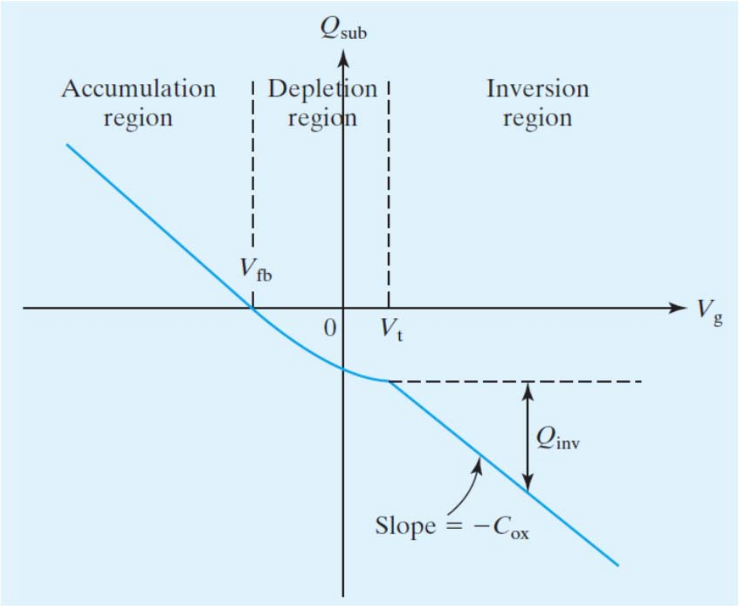


Review : Basic MOS Capacitor Theory

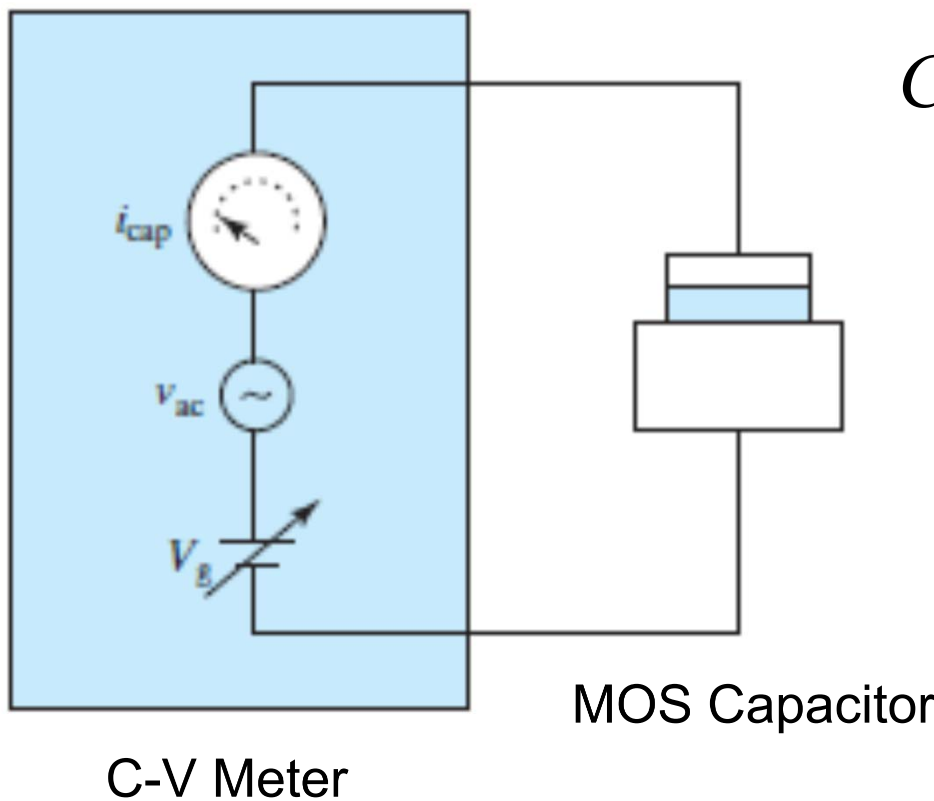


total substrate charge, Q_s

$$Q_s = Q_{acc} + Q_{dep} + Q_{inv}$$



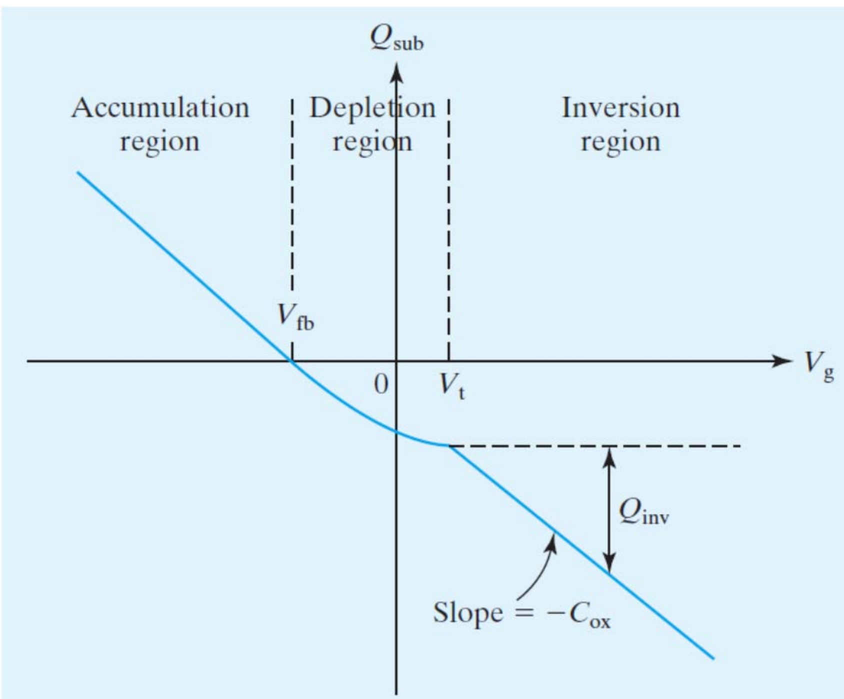
MOS CV Characteristics

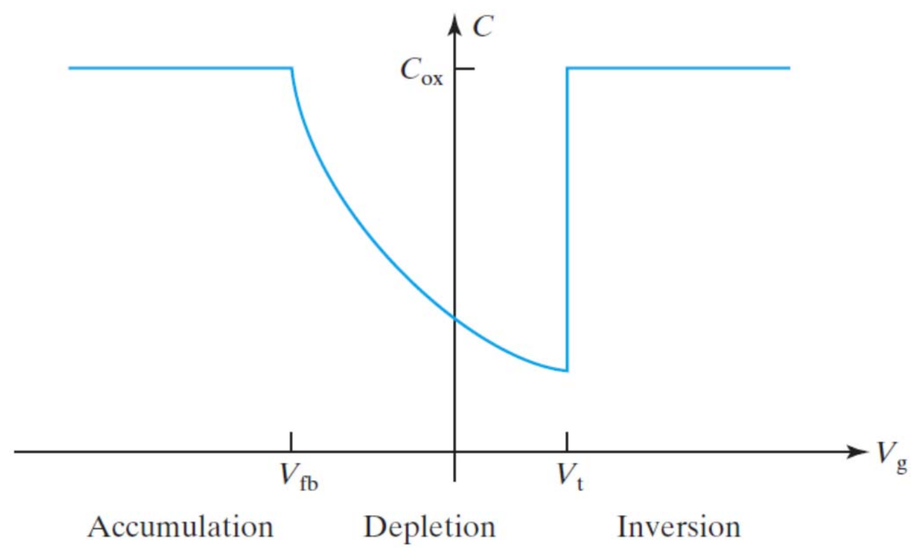


$$C = \frac{dQ_g}{dV_g} = -\frac{dQ_s}{dV_g}$$

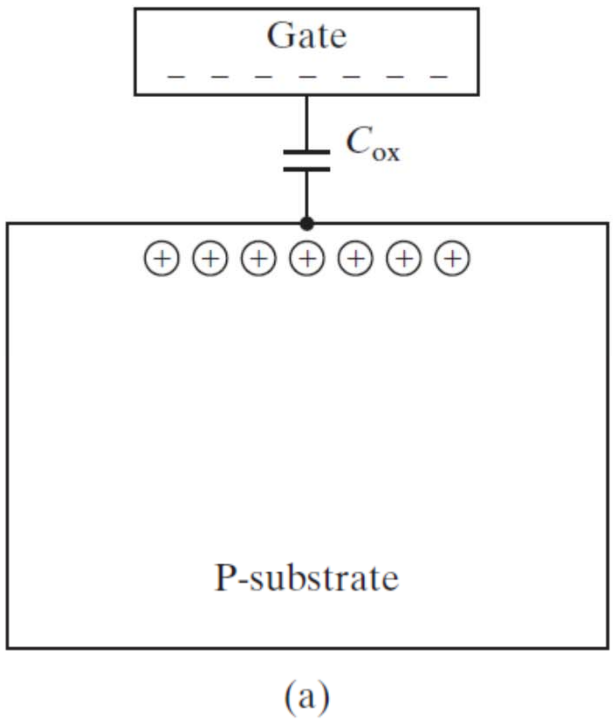
MOS CV Characteristics

$$C = \frac{dQ_g}{dV_g} = -\frac{dQ_s}{dV_g}$$

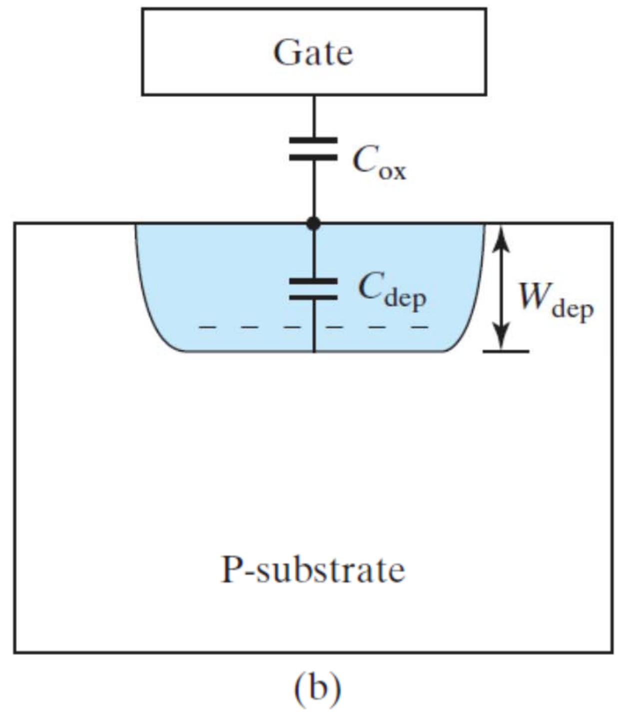




The quasi-static MOS C–V characteristics.

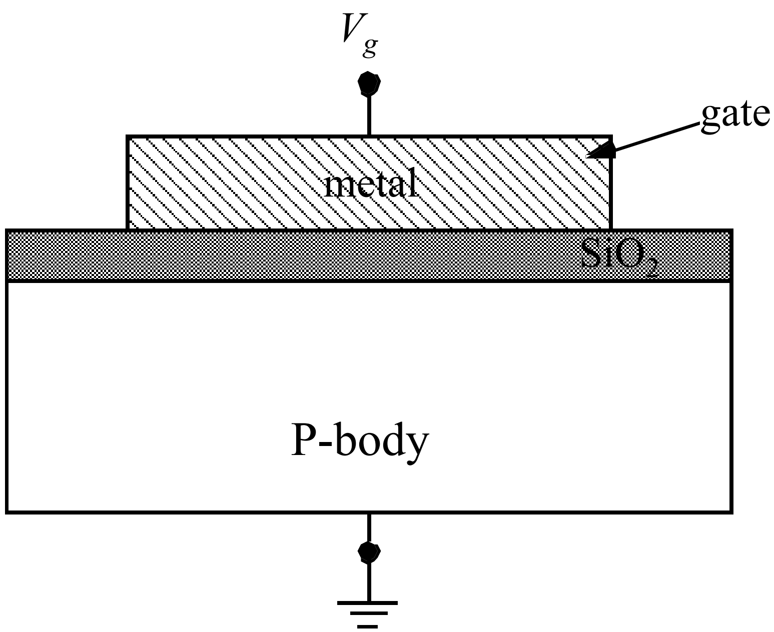


(a) Accumulation region



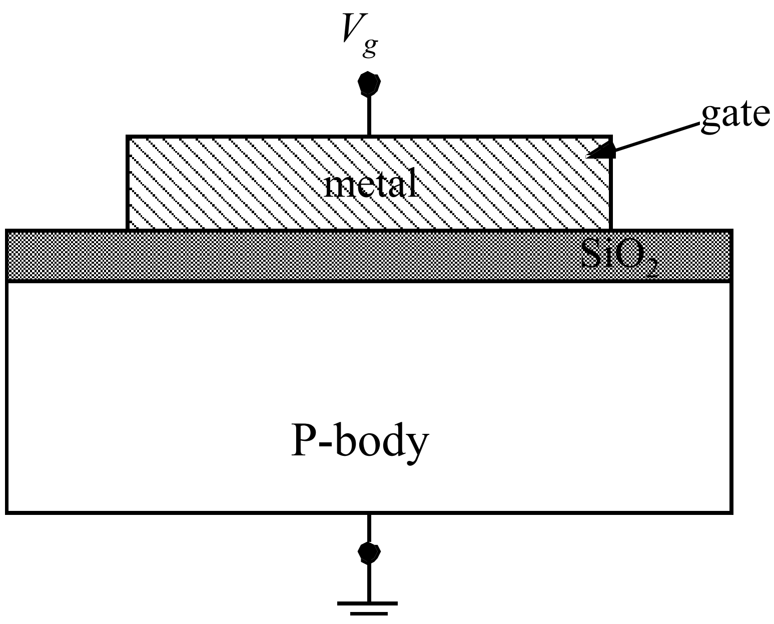
(b) depletion region

Inversion region

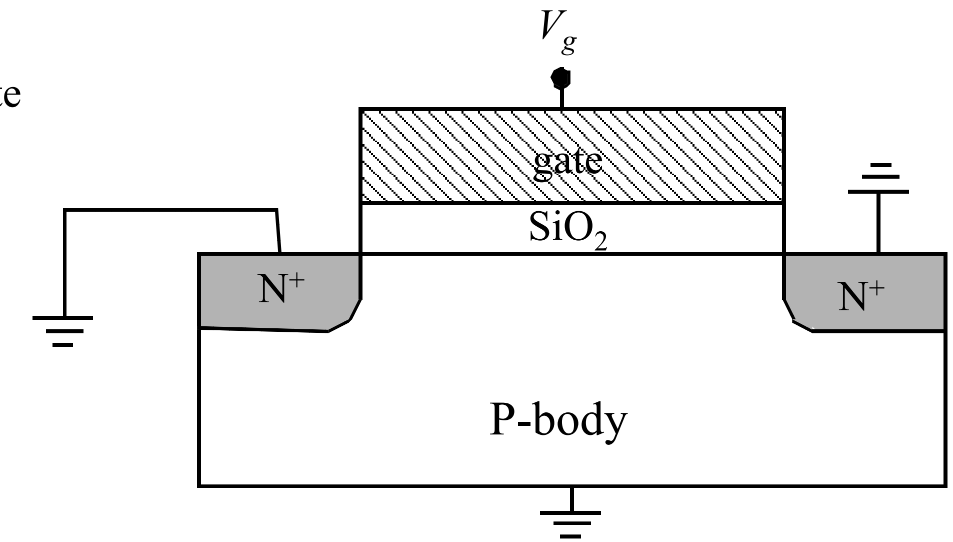


MOS capacitor

Inversion region



MOS capacitor



MOS transistor

~the end~