Recitation Class 7

Zexi Li

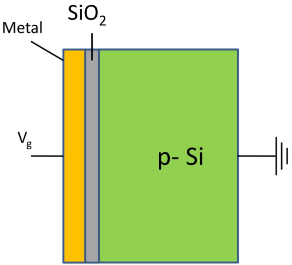
lzx12138@sjtu.edu.cn

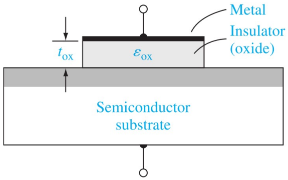
2021.07.20

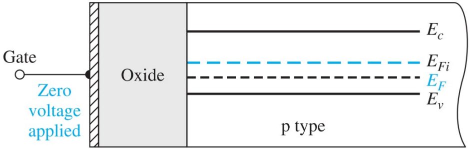
Outline

Table of Contents

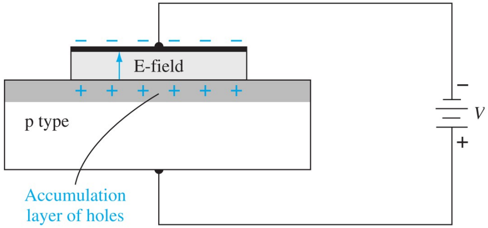
Metal–Oxide–Semiconductor



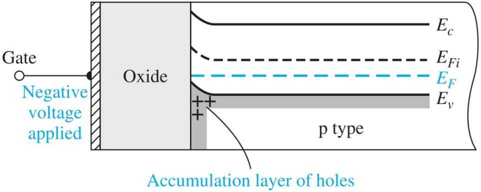




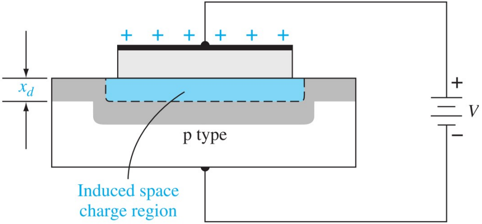
Negative Gate Voltage



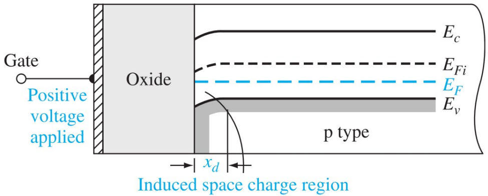
Negative Gate Voltage



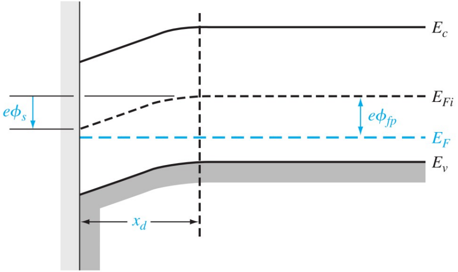
Positive Gate Voltage



Positive Gate Voltage



Depletion Layer Thickness

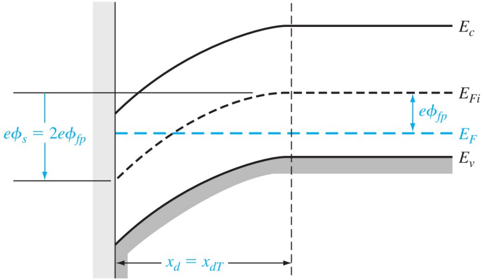


$$\phi_{fp} = V_t \ln\left(\frac{N_a}{n_i}\right)$$

$$x_d = \left(\frac{2\varepsilon_s \phi_s}{eN_a}\right)^{1/2}$$

ϕ_s: the surface potential, is the difference (in V) between E_{Fi} measured in the bulk semiconductor and E_{Fi} measured at the surface.

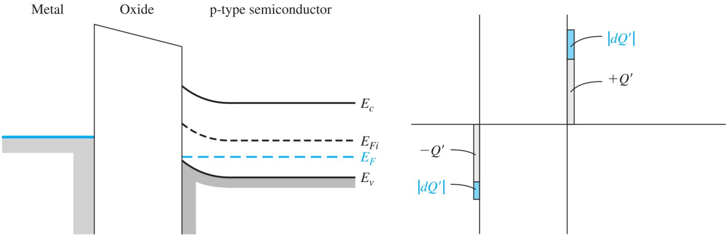
Threshold Inversion Point



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

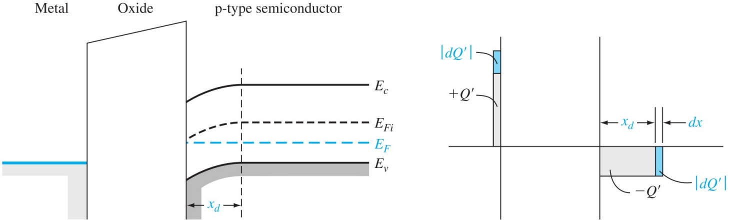
$$\boxed{x_{dT} = \left(\frac{4\varepsilon_s \phi_{fp}}{eN_a}\right)^{1/2}}$$

Accumulation



$$C'(\mathrm{acc}) = C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$$

Depletion

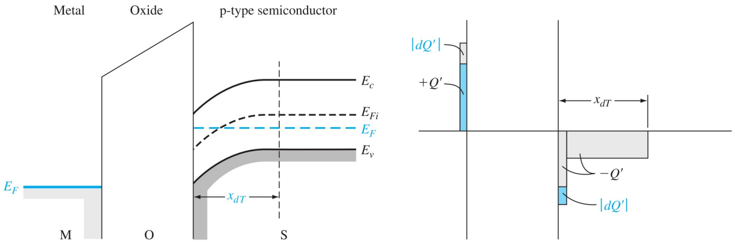


$$C'(\text{depl}) = \frac{C_{ox}C'_{SD}}{C_{ox} + C'_{SD}}$$

$$= \frac{\varepsilon_{ox}}{t_{ox} + \left(\frac{\varepsilon_{ox}}{\varepsilon_s}\right) x_d}$$

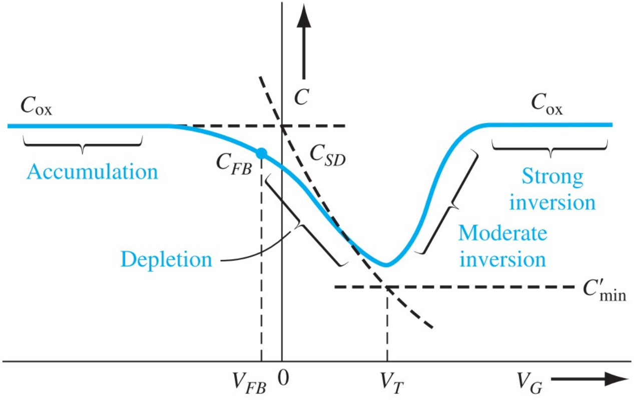
$$C'_{min} = \frac{\varepsilon_{ox}}{t_{ox} + \left(\frac{\varepsilon_{ox}}{\varepsilon_s}\right) x_{dT}}$$

Inversion



$$C'(\text{inv}) = C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$$

Ideal Low-Frequency C-V Curve



$$C'_{FB} = \frac{\varepsilon_{ox}}{t_{ox} + \left(\frac{\varepsilon_{ox}}{\varepsilon_s}\right)\sqrt{\left(\frac{kT}{e}\right)\left(\frac{\varepsilon_s}{eN_a}\right)}}$$

Exercise

Objective Calculate C_{ox}, C'_{min} and C'_{FB} for a MOS capacitor. Consider a p-type silicon substrate at $T = 200K$ doped to $N_a = 10^{16} cm^{-3}$. The oxide is silicon dioxide with a thickness of $t_{ox} = 18nm = 180$Å, and the gate is aluminum. (Example 10.6 on textbook)

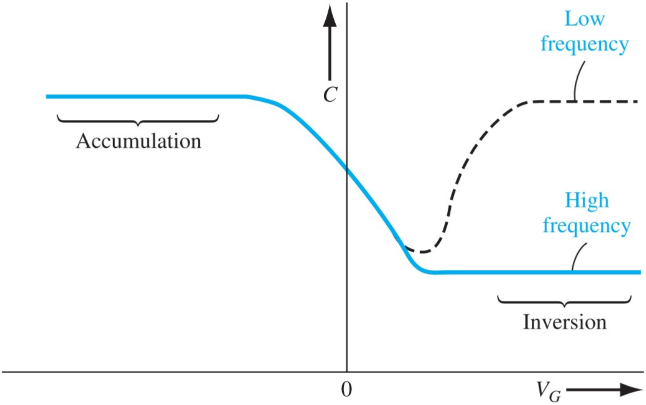
Answer:

.

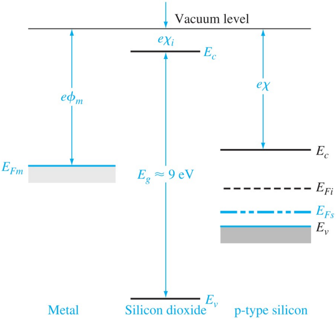
Frequency Effects

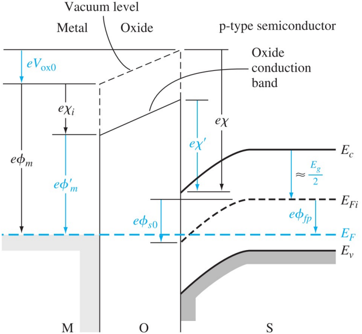
Two sources of electrons

1. Diffusion of minority carrier electrons.
2. Thermal generation of electron-hole pairs within the space charge region.



Work Function Difference



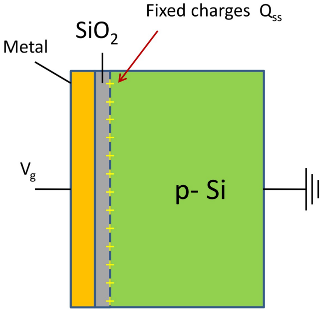


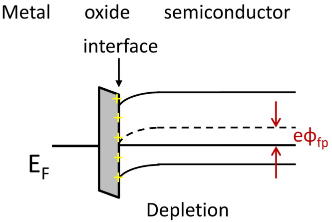
$$\phi_{ms} = \phi'_m - \left(\chi' + \frac{E_g}{2e} + \phi_{fp} \right)$$

$$\phi_{ms} = \phi'_m - \left(\chi' + \frac{E_g}{2e} - \phi_{fn} \right)$$

Not required.

Fixed Charge

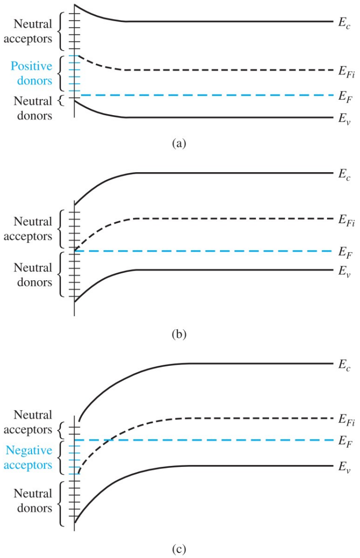


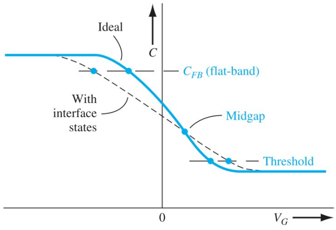


Adjustment on V_T

$$\boxed{\begin{aligned} \left|Q'_{SD}(\max)\right| &= eN_a x_{dT} = 2\sqrt{e\varepsilon_s N_a \phi_{fp}} \\ V_{TN} &= \frac{|Q'_{SD}(\max)|}{C_{ox}} + V_{FB} + 2\phi_{fp} \\ V_{TP} &= -\frac{|Q'_{SD}(\max)|}{C_{ox}} + V_{FB} - 2\phi_{fn} \\ V_{FB} &= \phi_{ms} - \frac{Q'_{ss}}{C_{ox}} \cdot \frac{x}{d} \end{aligned}}$$

Surface States





Example

Objective Calculate the threshold voltage of a MOS system using an aluminum gate.
Consider a p-type silicon substrate at $T = 300K$ doped to $N_a = 10^{15} cm^{-3}$. Let $Q'_{ss} = 10^{10} cm^{-2}$, $t_{ox} = 12cm = 120$Å, and assume the oxide is silicon dioxide. $\phi_{ms} = -0.88V$. (Example 10.4 on textbook)

Answer: .

End