Metal-Oxide-Semiconductor Structure

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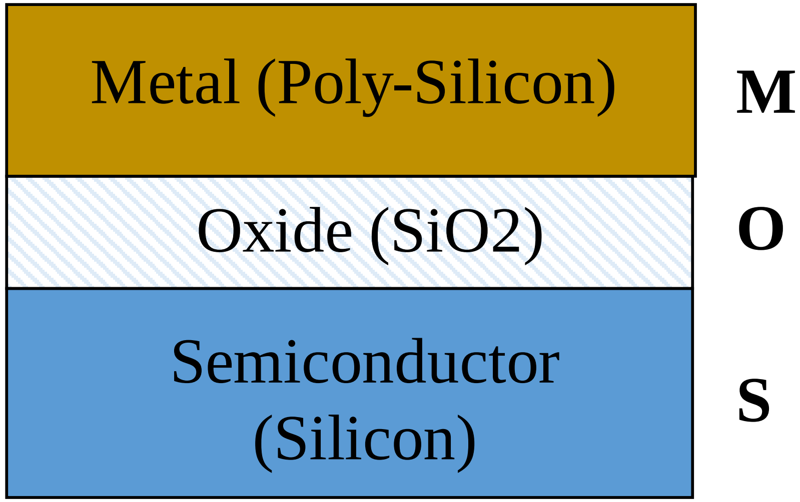
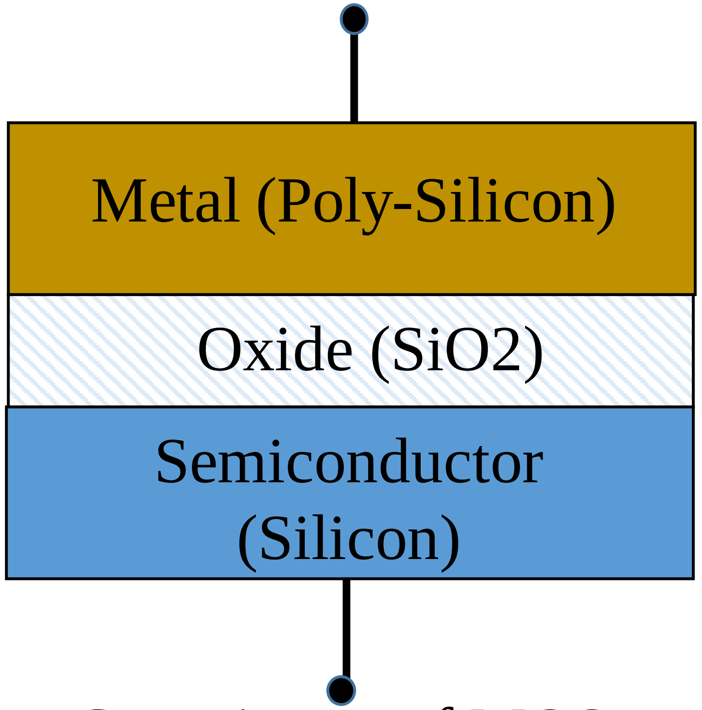
Metal-Oxide-Semiconductor (MOS) Device Structure

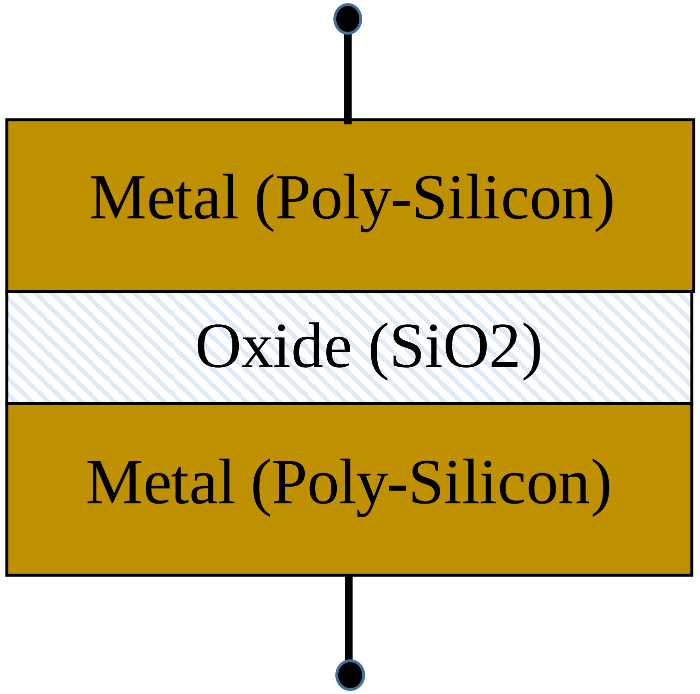
Metal-Oxide-Semiconductor (MOS) Junction

- MOS junction simply a capacitor
- No current-voltage relationship, only capacitor-voltage relationship

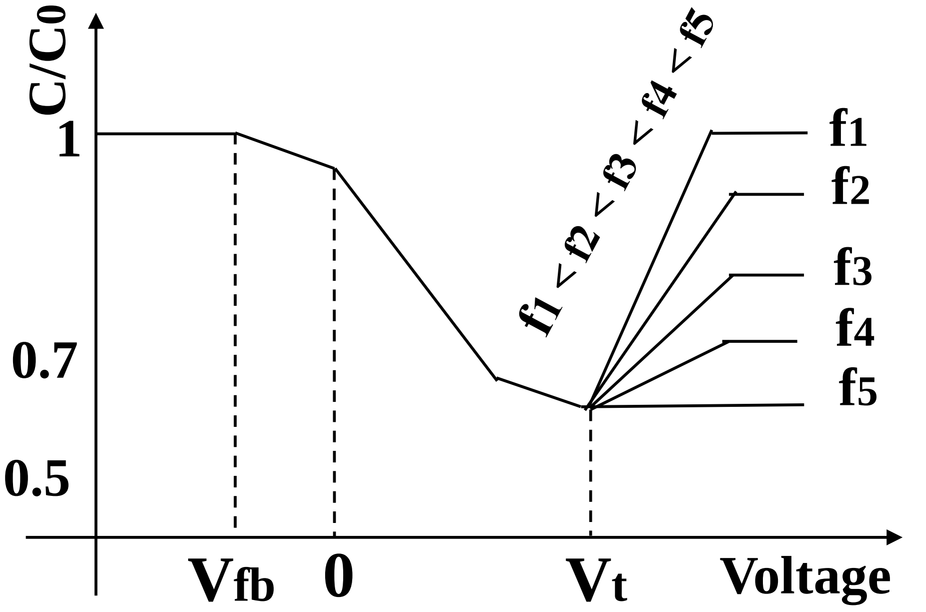




Capacitance of MOS structure = C

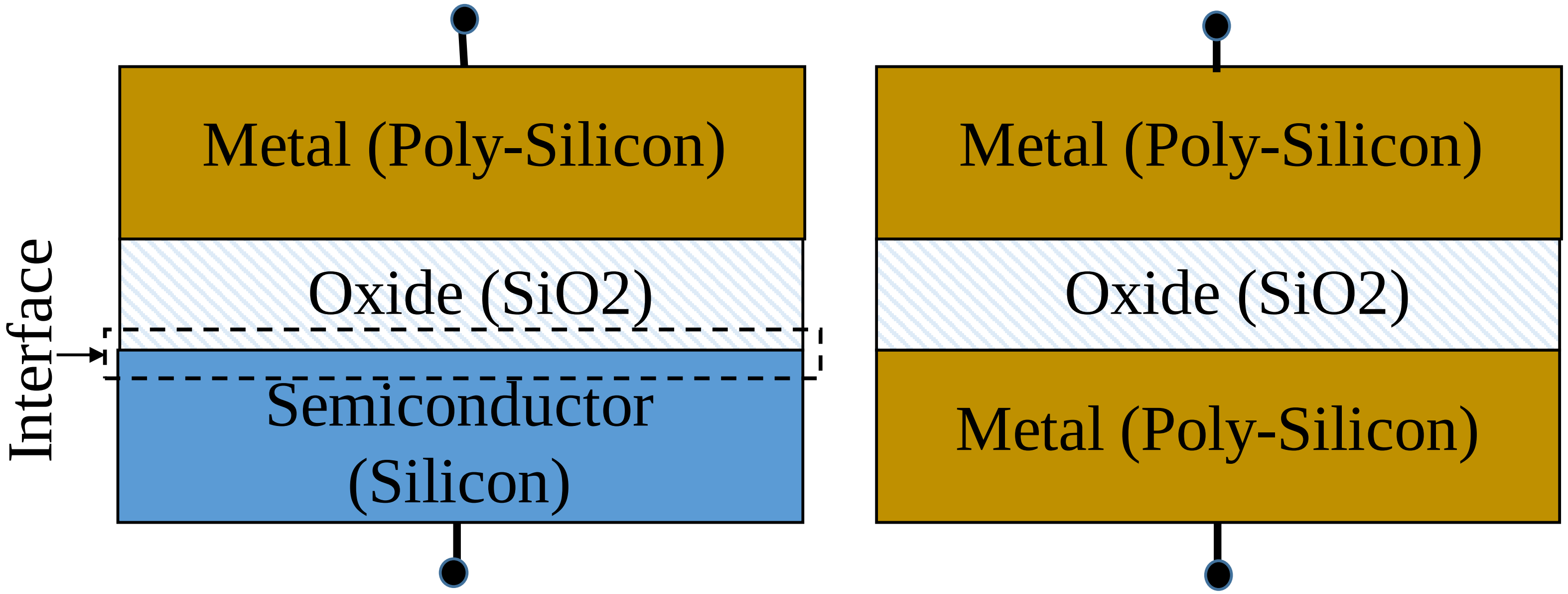


Capacitance of MOM structure = C_0



C-V Characteristics of a MOS

MOS Device Structure and Fabrication



Capacitance of MOS structure = C

Capacitance of MOM structure = C_0

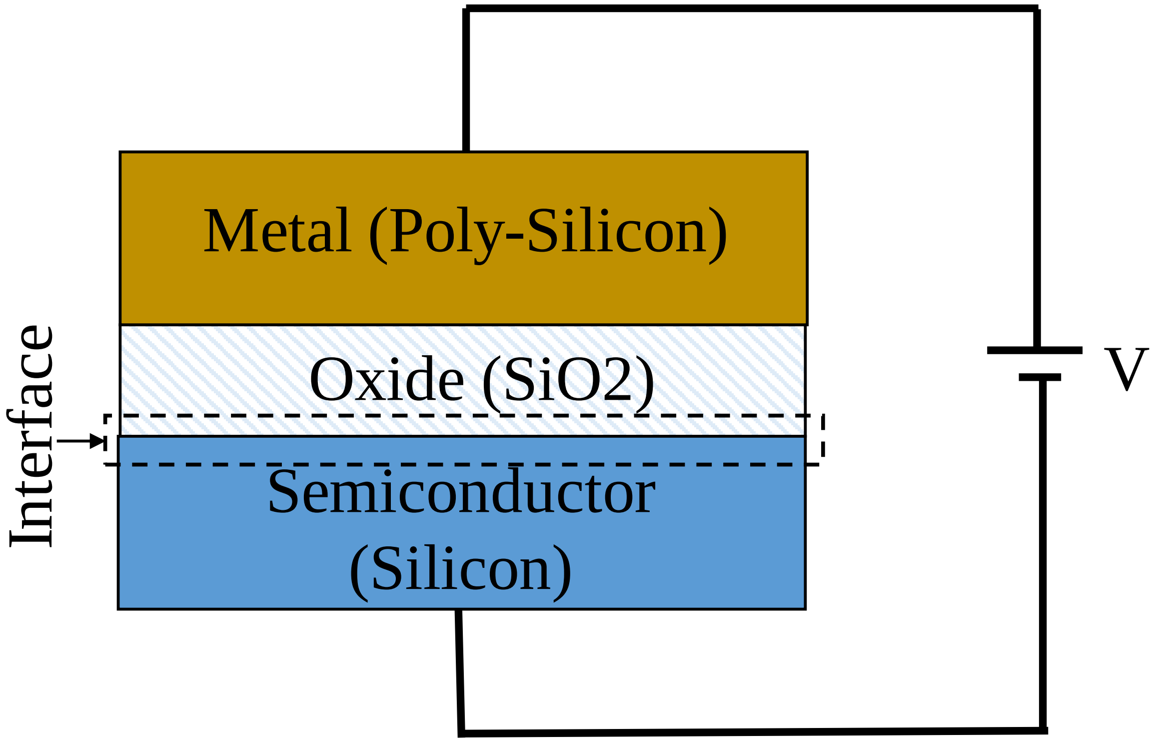
Fabrication:

- Oxidation: process to create SiO2 on top of Silicon.
- Metallization: process to deposit poly-silicon on top of SiO2.

Device Structure:

- Gate and substrate are different material so there is a contact potential between them. This expressed as metal to semiconductor work function (ϕms)
- Interface: between SiO2 and Silicon

Ideal MOS Junction or Capacitor



- *Φms*: Metal-to-semiconductor work function = 0
- *Qit:* Interface trapped charge = 0
- *Qot:* Oxide trapped charge = 0
- *Qf*: Fixed charge at the interface = 0
- *Qm*: Mobile charge in the oxide = 0

In this ideal condition we will analyze:

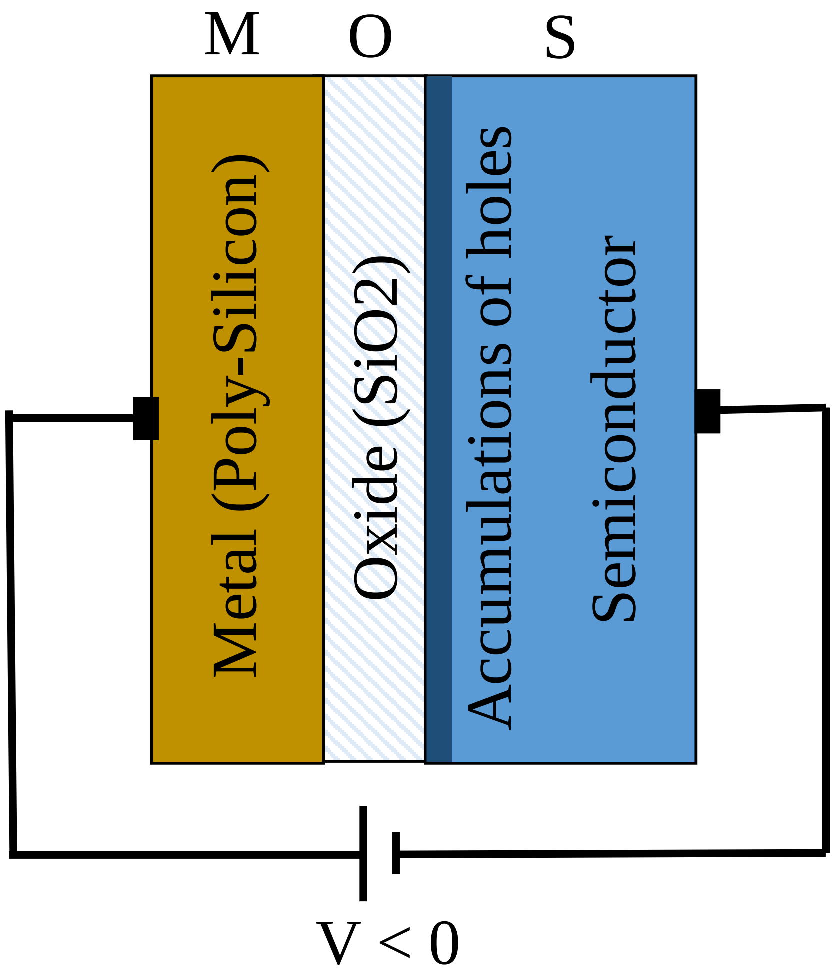
1. Case1: ($V < 0$) → Accumulation
2. Case2: ($V > 0$) → Depletion and weak inversion
3. Case3: ($V \geq VT$) → Strong inversion
4. Flat-band and Threshold voltage

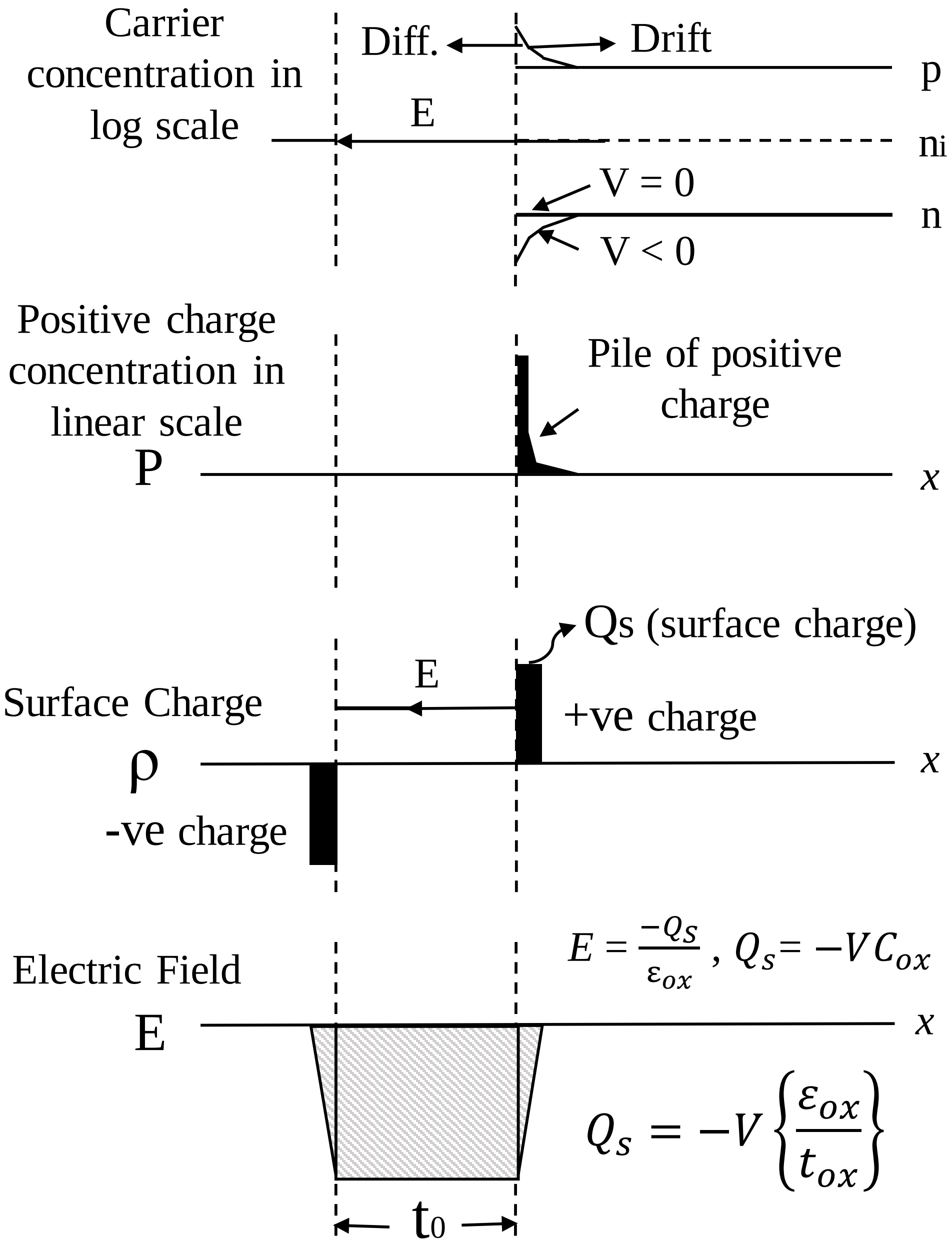
- No charge in the device if V= 0
- Substrate is uniformly doped

Case1: Accumulation Mode of Operation

Accumulation Mode (V < 0):

- Pile of majority carrier at the interface
- Charge at the surface directly proportional to voltage

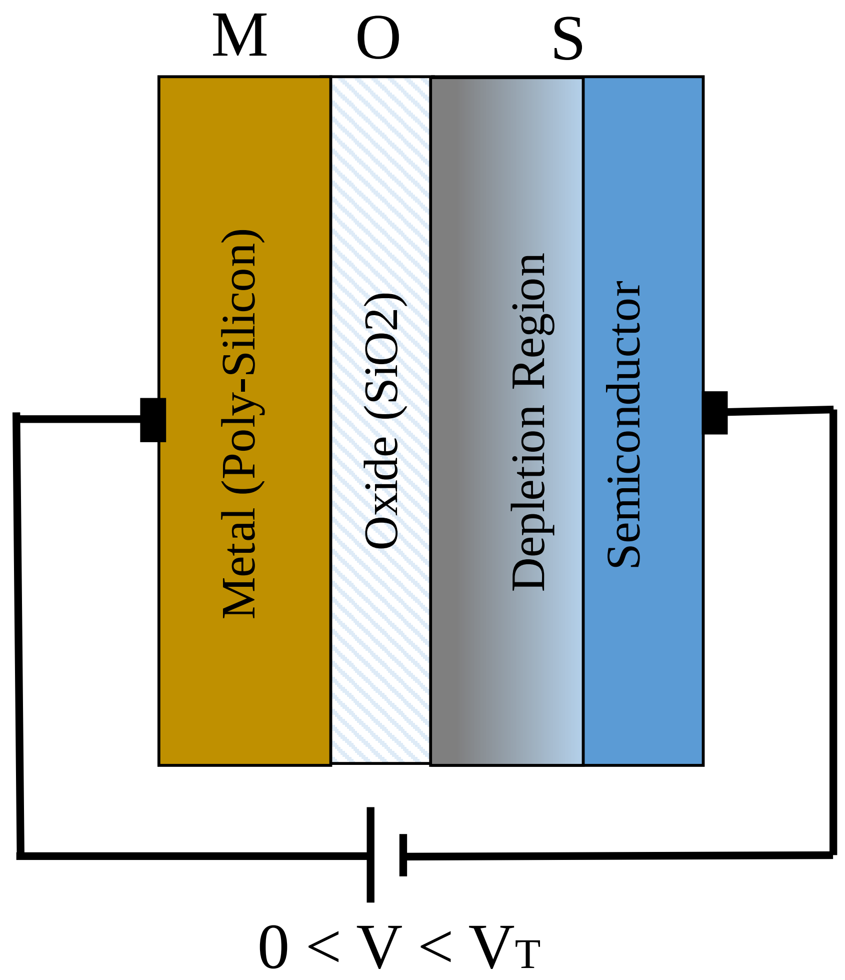




Case2: Depletion Mode of Operation

Depletion Mode ($0 < V < V_T$):

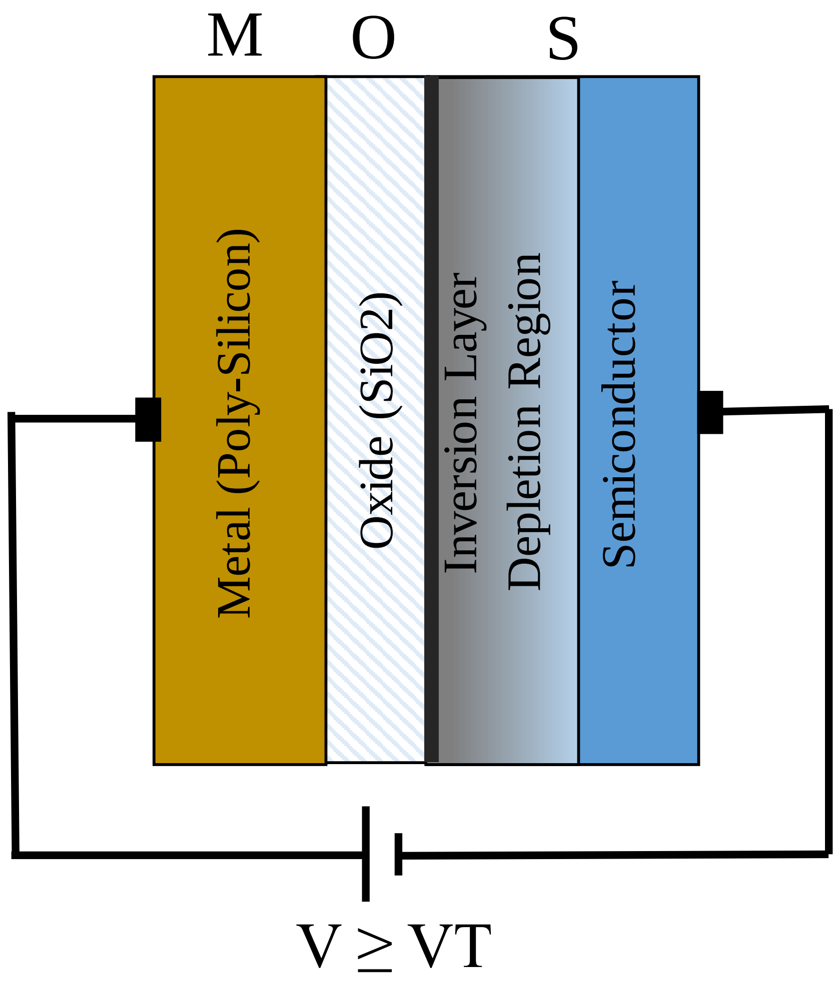
- The semiconductor surface starts to deplete and the type of charge at the surface is –ve (due to acceptor ions) and gradually increase with the increase of voltage.
- The voltage at which the surface carrier concentration is exactly equal to bulk carrier concentration, is called weak inversion voltage and form this point the weak inversion started.
- Charge at the surface directly proportional to voltage
- The voltage at which the surface concentration exactly equal to the bulk concentration, that is called threshold voltage
- This is called inversion point and at this point depletion mode ends and strong inversion started.



Case3: Strong Inversion Mode of Operation

Strong Inversion Mode ($V \geq V_T$):

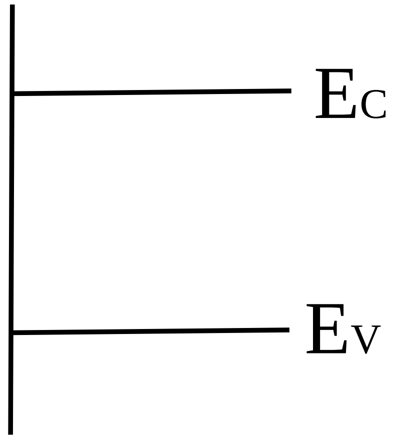
- At threshold voltage a channel form at the surface of the semiconductor due to inversion charges.
- Before threshold voltage the charge comes from negatively charged ionized acceptors.
- After threshold voltage, the more charge comes from the electrons rather than depleting the holes.
- The extra negative charge required for the semiconductor is comes from the mobile electrons which are very close to the surface.



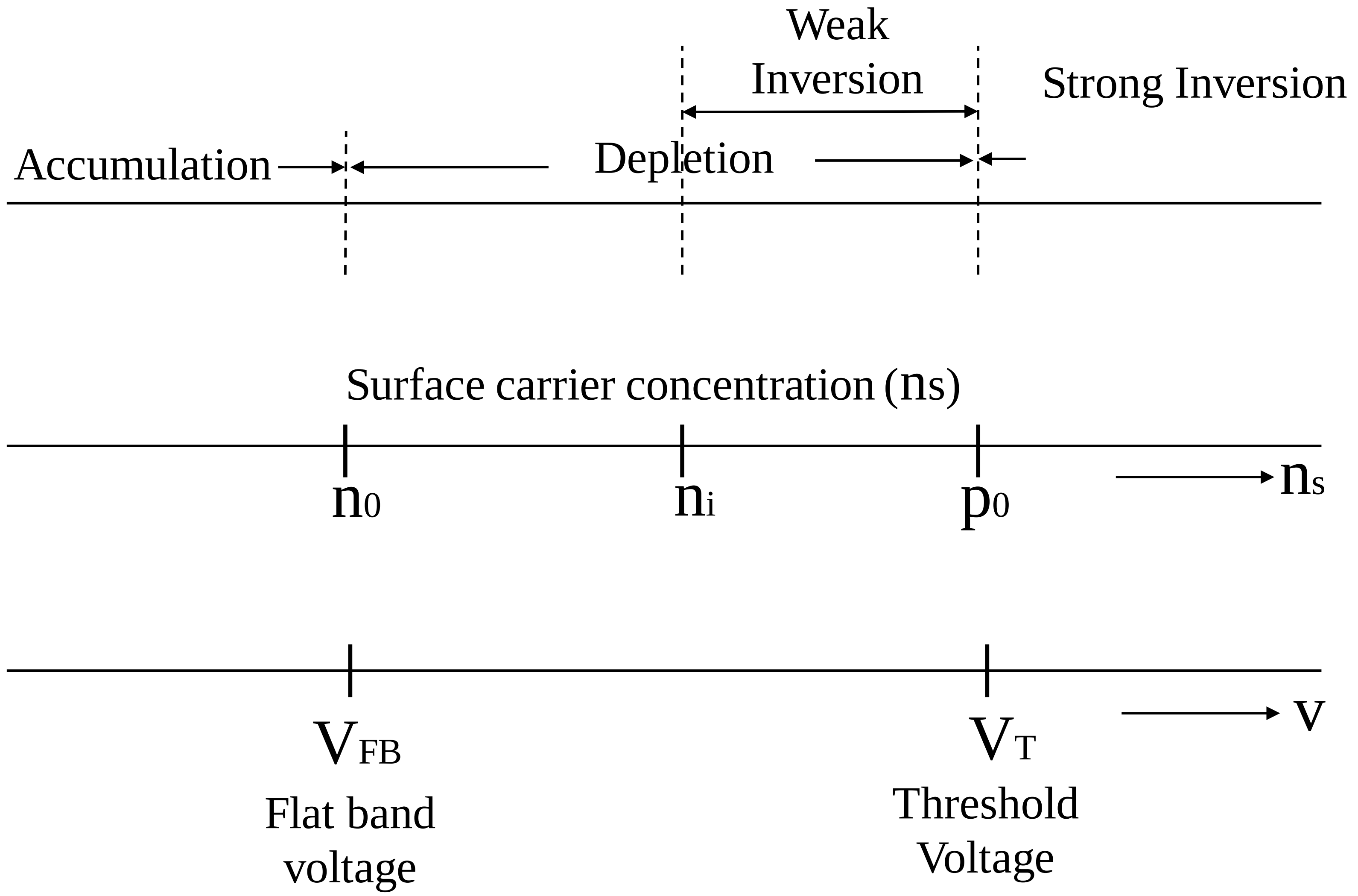
Summary of the MOS Operation Modes

Depletion Mode (V > 0):

- Flat band voltage is 0 for ideal MOS structure
- Flat band means flatness of conduction and valence band edges at semiconductor surface



Flat band condition



Q-V Characteristics of MOS Structure

Surface Charges at different regions:

Accumulation: $Q_{acc.} = C_o V$

Depletion: $-Q_d = \sqrt{2q\epsilon_{si}N_a\phi_t}$

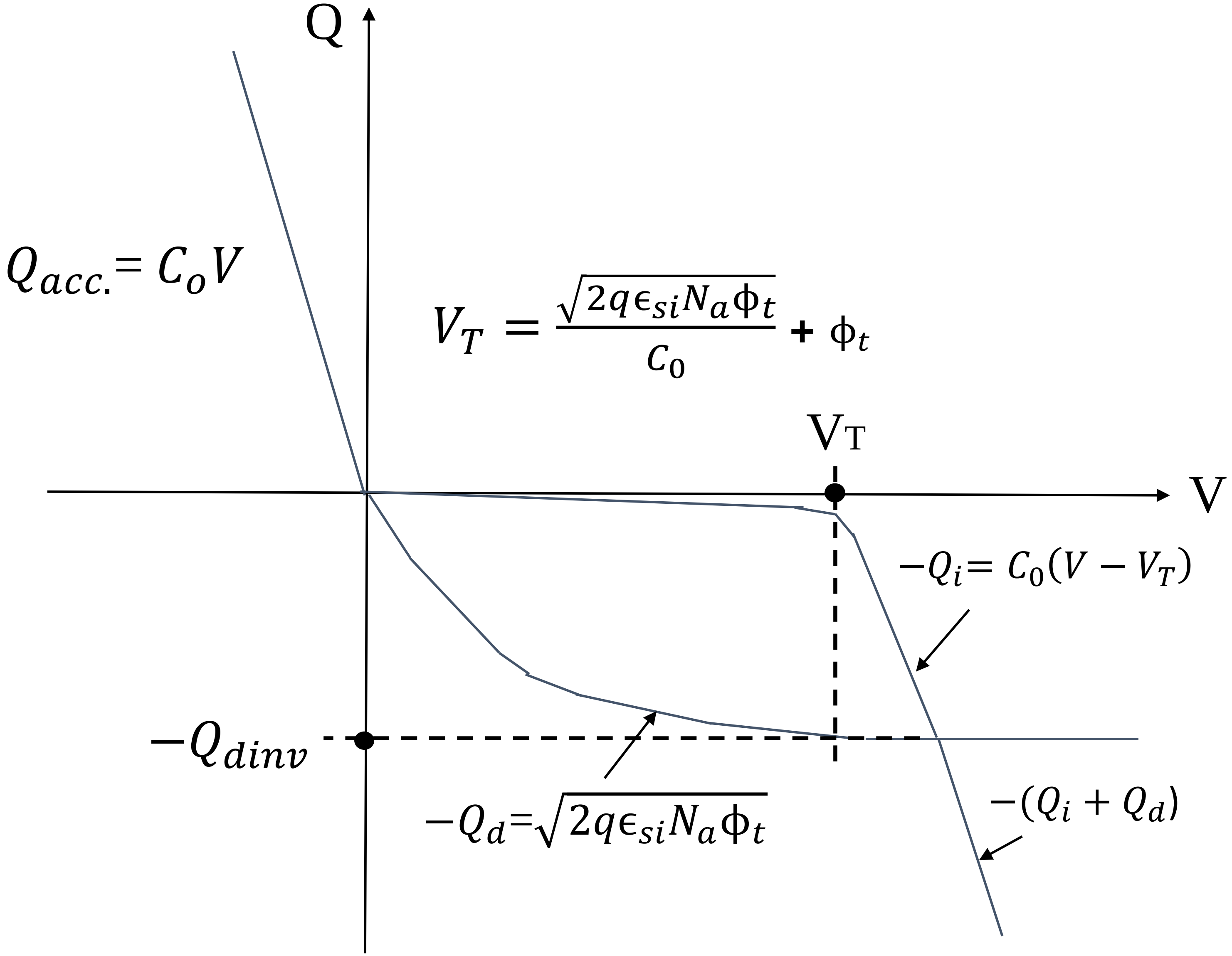
Inversion: $-Q_i = C_0(V - V_T)$

Threshold Voltage:

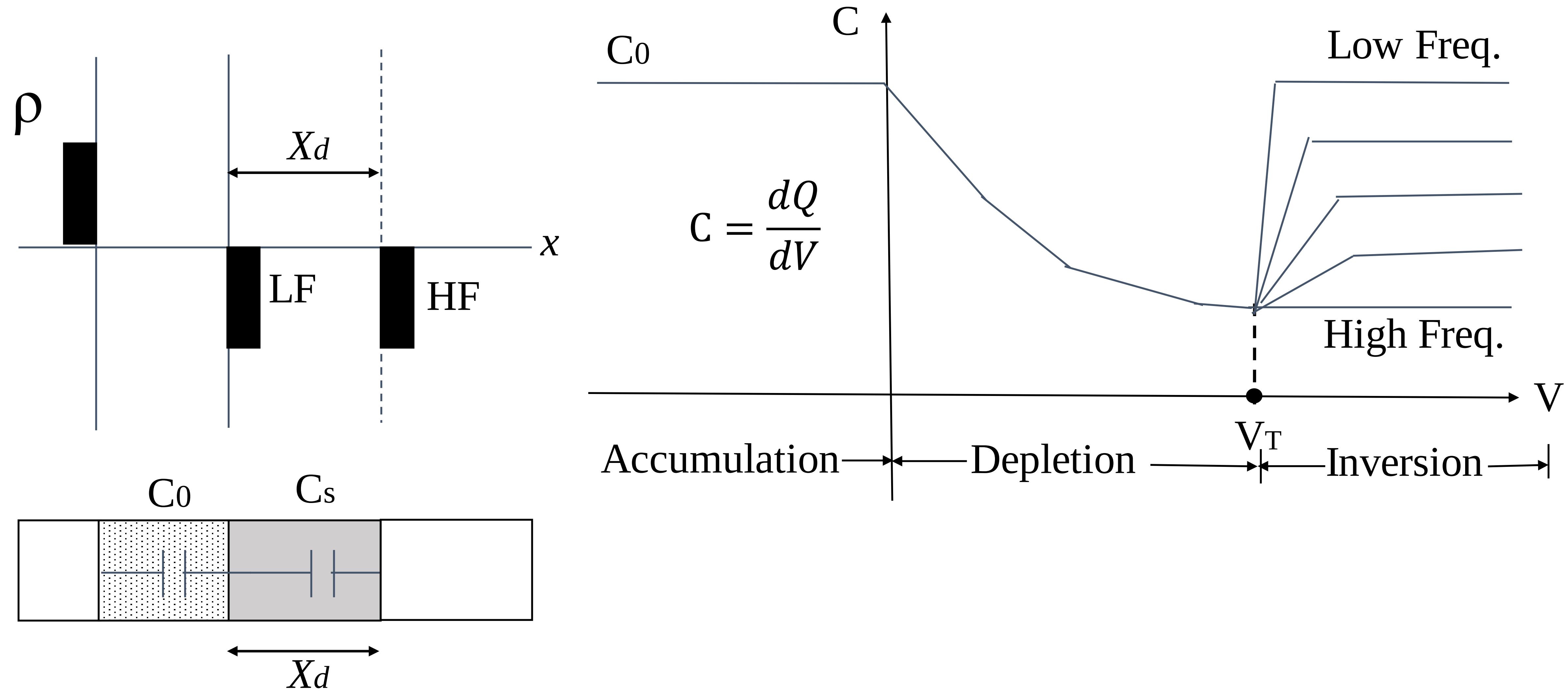
$$V_T = \frac{\sqrt{2q\epsilon_{si}N_a\phi_t}}{C_0} + \phi_t$$

Potential across oxide

Surface Potential



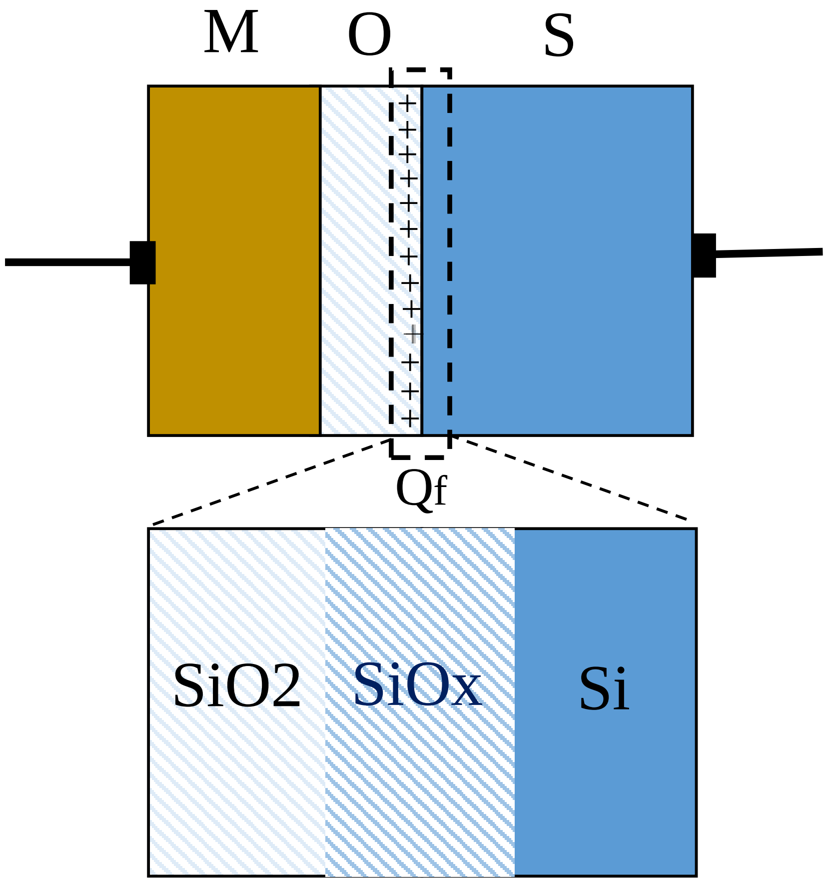
C-V Characteristics of MOS Structure

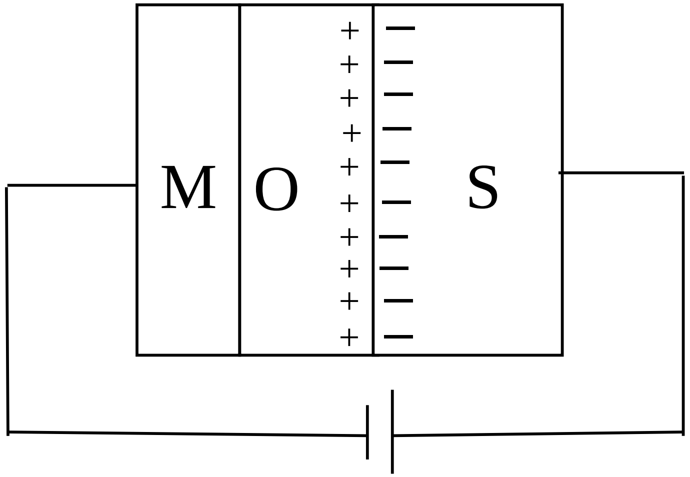


Non Ideal MOS Structure

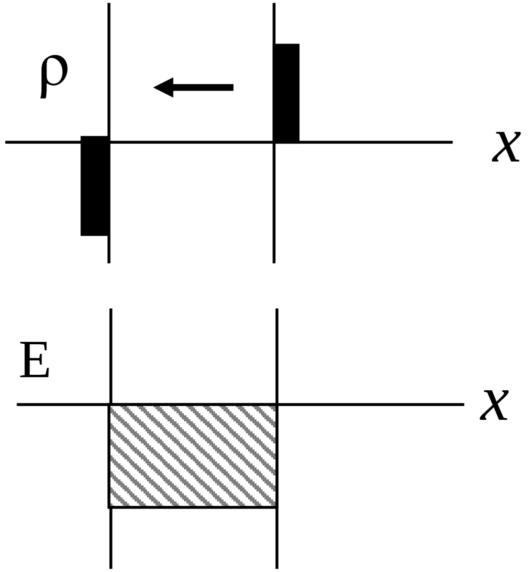
Effect of fixed charge Qf

- To cerate a zero charge on silicon a negative voltage is required to give at gate terminal.
- By applying a negative volute at gate the surface charge at silicon will be zero.
- Zero charge in the semiconductor corresponds to flat-band condition of a MOS junction.





$$V_{FB} = -Q_f/C_0$$

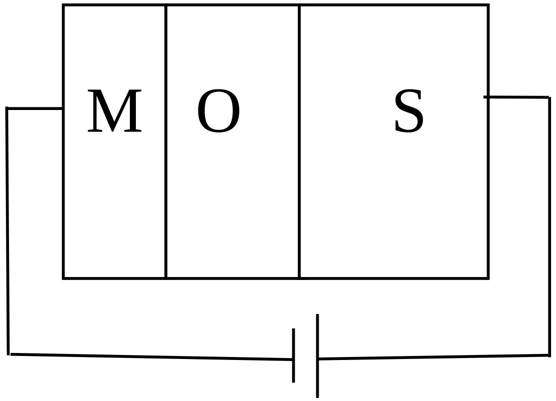


- SiOx, x varies from 0 to 2
- Qf is called fixed charge and it has no movement and not vary with voltages

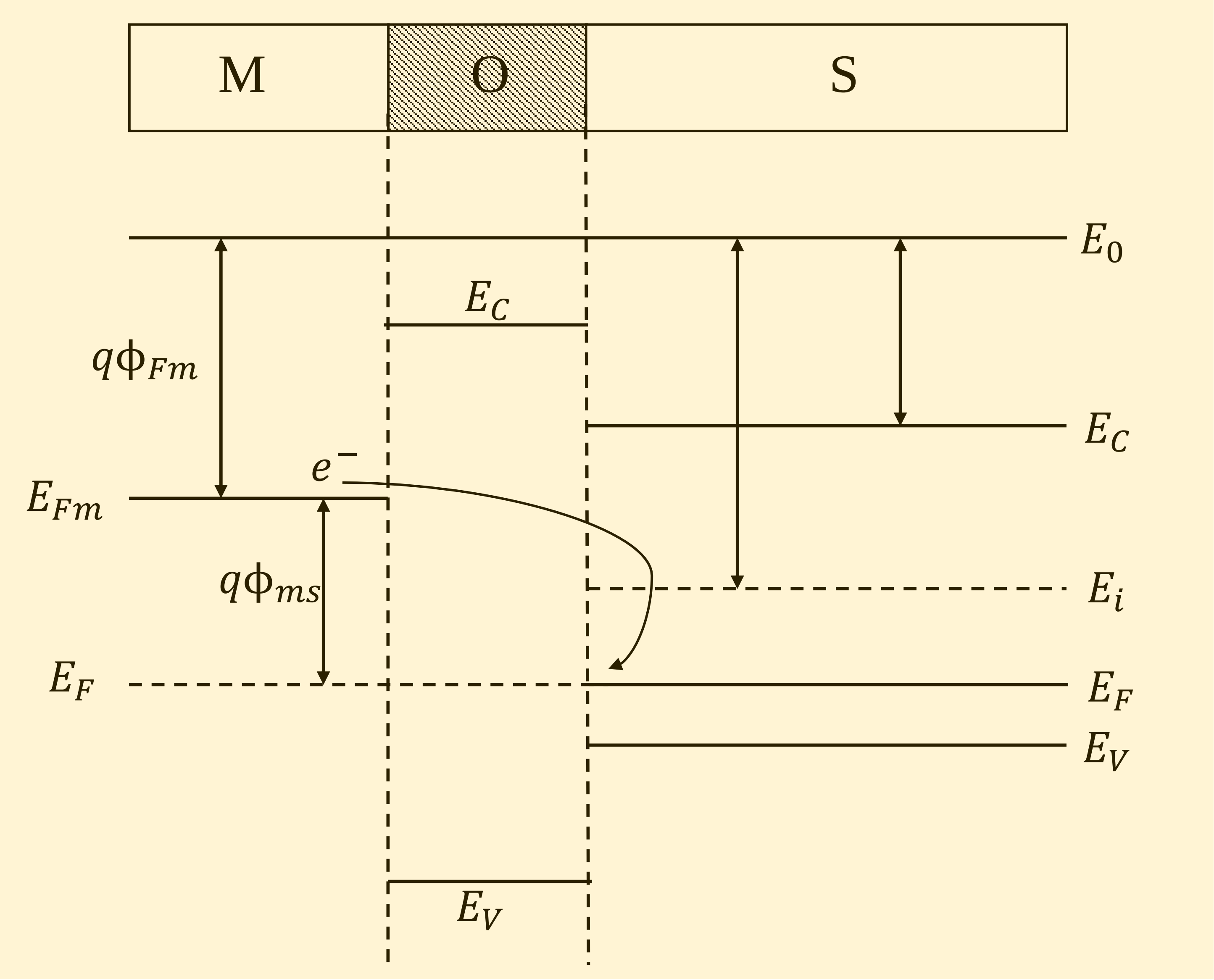
Non Ideal MOS Structure

Effect of work metal-semiconductor work function difference ϕms

- Electrons are always moves from higher energy level to lower energy level.
- Electrons are transferred through wire.
- To remove the electrons from semiconductor surface we have to provide a –ve voltage to the gate.



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



Nonideal MOS Band Diagram

Summary of Nonideal MOS Capacitor

1. Effect of fixed oxide charge Q_F

- $V_{FB} = \frac{-Q_F}{C_{0x}}$

2. Effect of work metal-semiconductor work function difference ϕms

- $V_{FB} = \phi_{ms} = \phi_m - \phi_s$

3. In presence of both fixed charge and metal-to-semiconductor work function;

- $V_{FB} = \frac{-Q_F}{C_{0x}} + \phi_{ms}$

4. So threshold voltage od a nonideal MOS capacitor will be;

- $V_T = V_{Tideal} + V_{FB} = \varphi_{ox} + \varphi_s + \frac{-Q_F}{C_{0x}} + \phi_{ms}$

Thank You