MOS Capacitors

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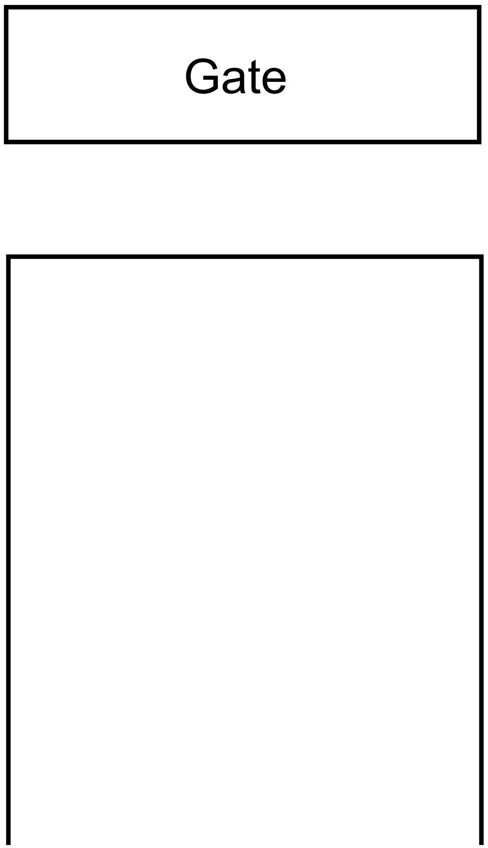
Metal Oxide Semiconductor Capacitors

MOS Capacitors

- Used as capacitors (sometimes)
- Other main ingredient in a MOS transistor (besides p-n junctions)
- Used in imagers (i.e. cameras) → Charge-Coupled Devices (CCD)

MOSCap Construction

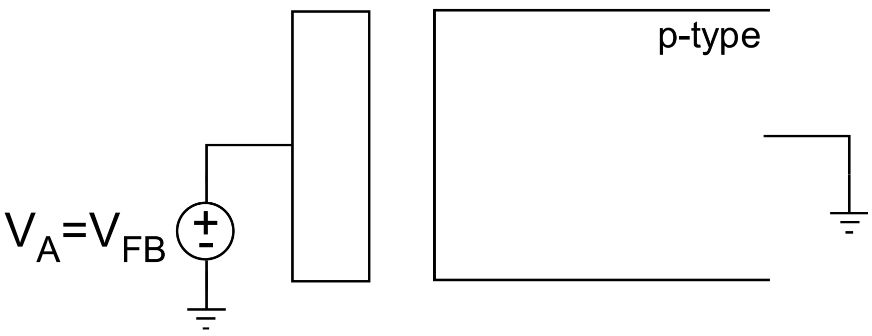


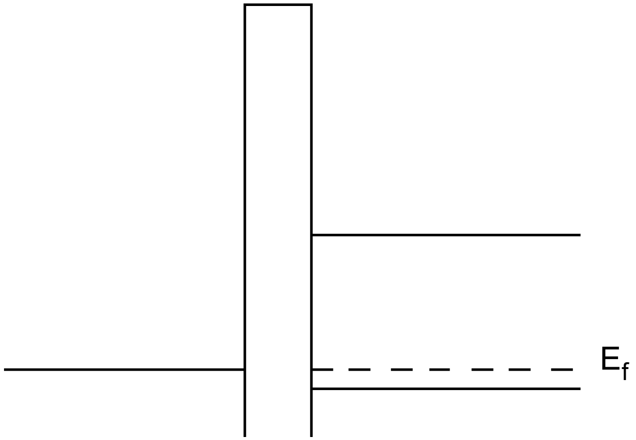
← Polysilicon (“poly”), a conductor

← SiO_2, an insulator

← Semiconductor

Under Bias – Flat Band





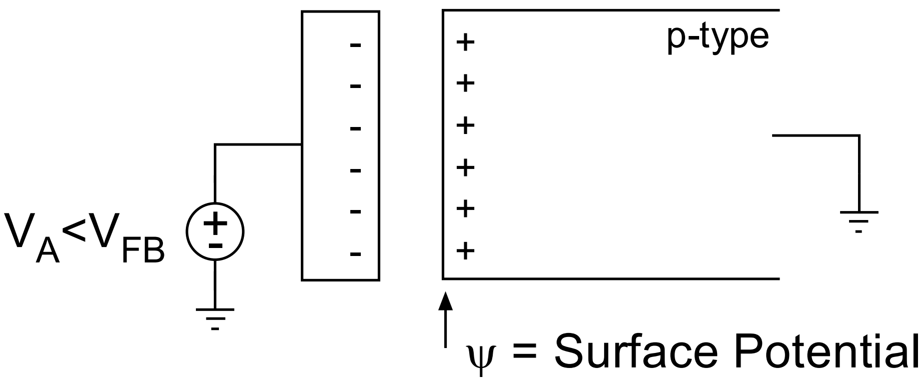
- Bands are flat
- SiO_2 provides large barrier ~3.04eV

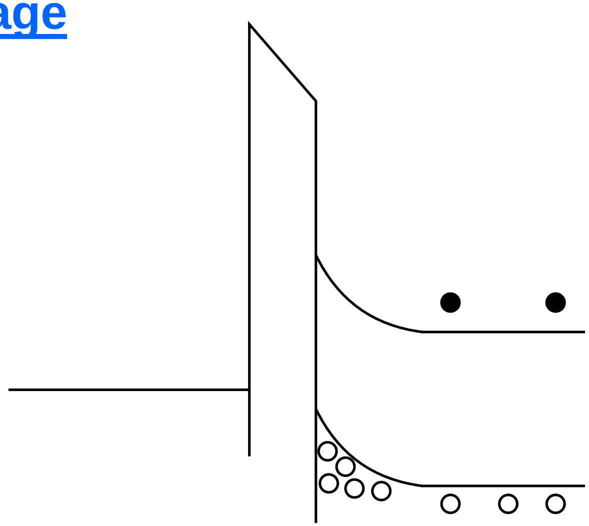
Flat Band (V_{FB})

- Some voltage that provides flat bands
- Simply used as a reference
- May not be known ahead of time

Accumulation

Apply Negative Voltage



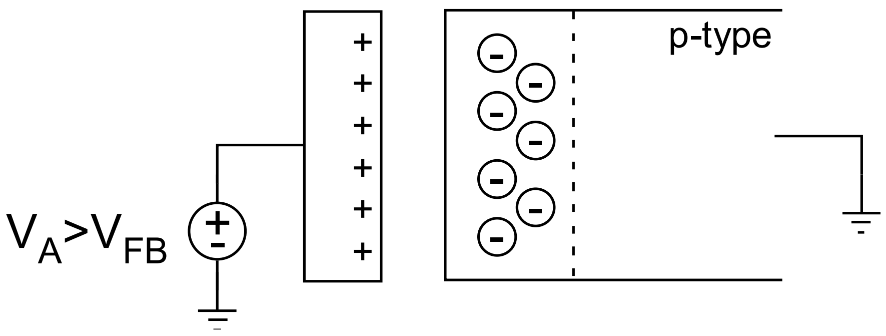


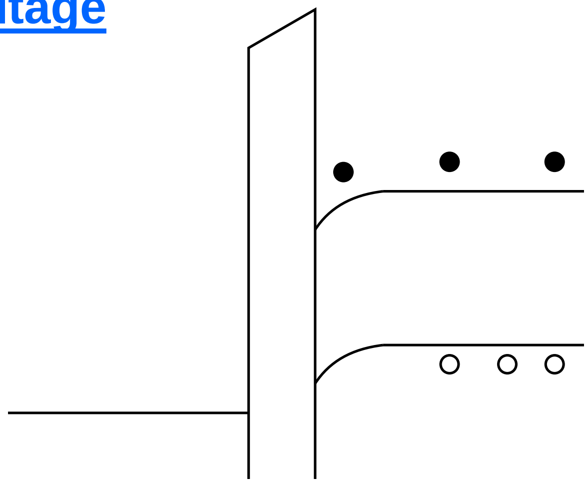
- e^- will not get close to the boundary (drift)
- h^+ will accumulate at the boundary (fall into the groove)

- Lower the voltage on the “metal” or “poly” or “gate”
- Adds e^- to the gate
- p-type material has many h^+
- h^+ rush to the SiO_2 interface to balance the e^- on the gate
- Acts as a linear capacitor (parallel plates)
- Majority carriers “accumulate” at the SiO_2 interface

Depletion

Apply Positive Voltage

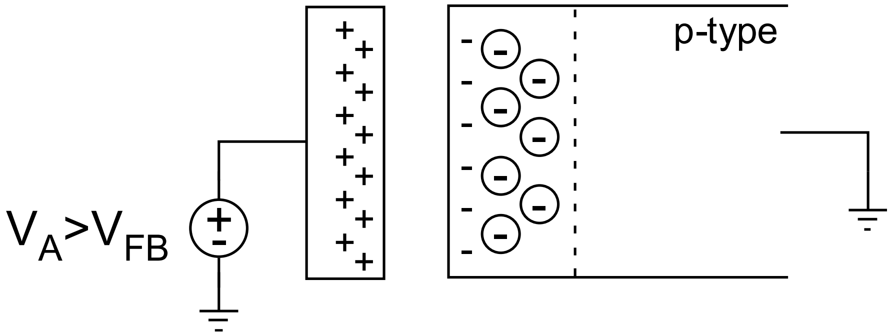


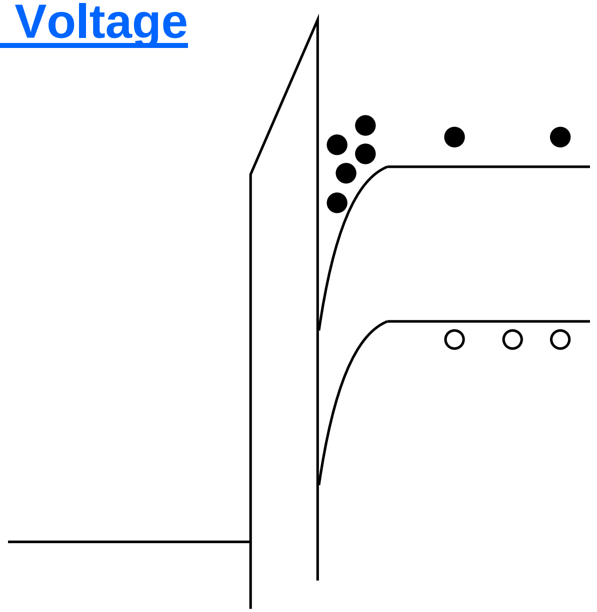


- Raise the gate voltage
- Adds h^+ to the gate
- Pushes the h^+ (majority carriers) away from the interface
- Leaves behind negative ions (immobile) to counterbalance the charge
- Capacitance is composed of two parts
  - Linear oxide capacitance
  - Nonlinear depletion capacitance (capacitance over the depletion region)

Inversion

Apply Larger Positive Voltage



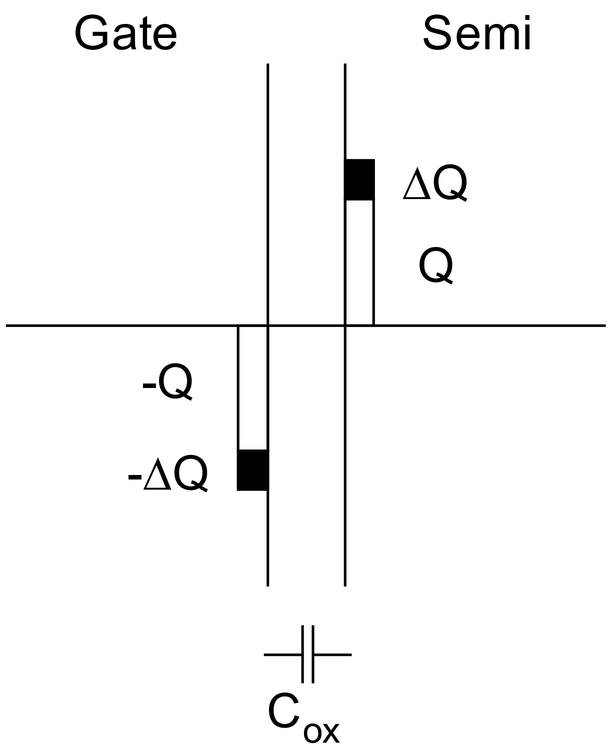


- Large number of h^+ on the gate
- Depletion region becomes wide
- Depletion region cannot provide enough negative charges to balance positive charges
- Positive charges attract minority carrier e^- to the surface
- Surface becomes virtually n-type
- Minority carriers are free to move around on the surface

Regions of Inversion

- Weak Inversion
  - # of minority carriers << # of exposed ions
- Moderate Inversion
  - # of minority carriers ≈ # of exposed ions
- Strong Inversion
  - # of minority carriers >> # of exposed ions

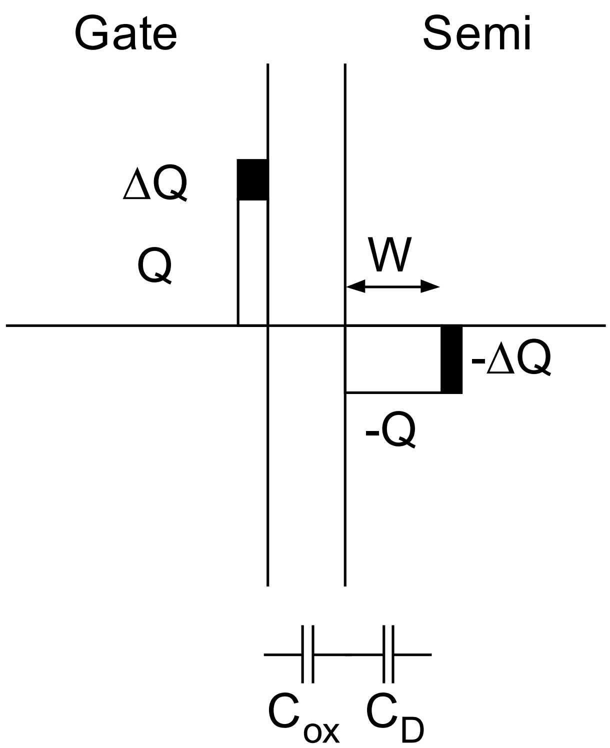
MOSCap Capacitance



Accumulation

- ΔQ from the small-signal AC variations
- Looks like a linear, parallel-plate capacitor

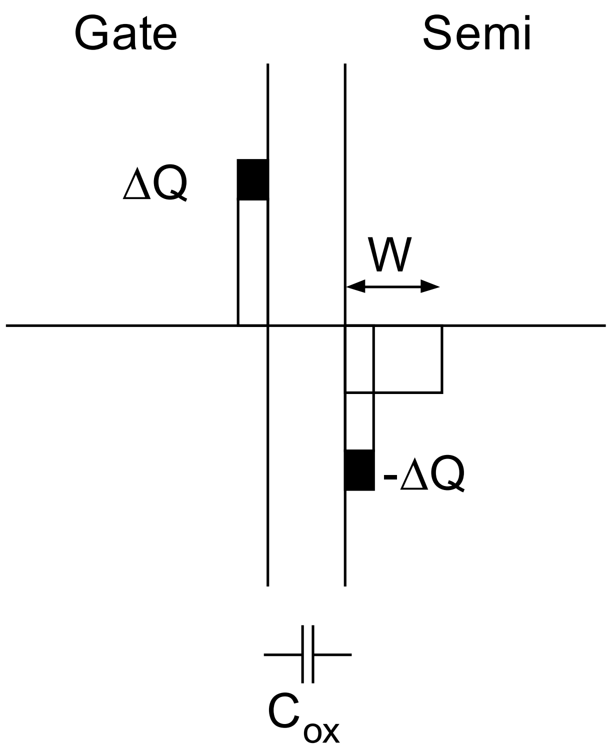
MOSCap Capacitance



Depletion

- Looks like 2 capacitors in series
  - Linear oxide capacitor
  - Nonlinear depletion capacitance
- Total capacitance varies for differing gate voltages

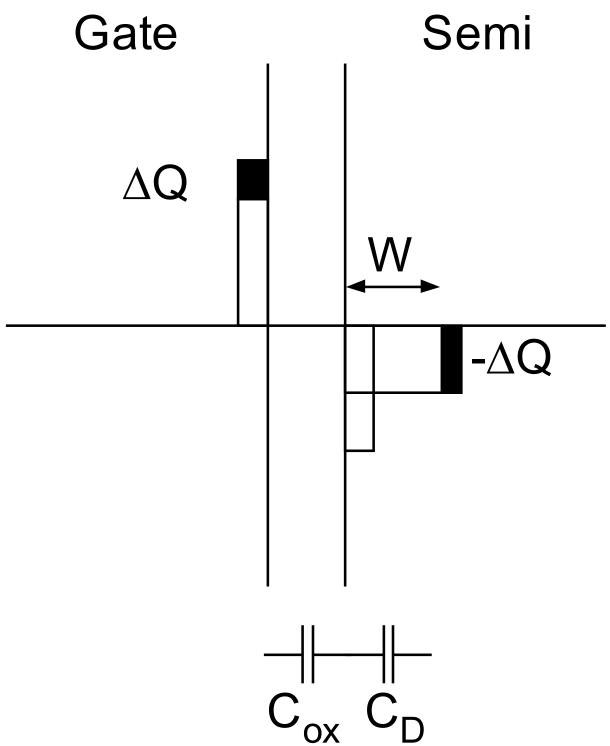
MOSCap Capacitance



Inversion (Low Frequency)

- At low frequencies, there is time for the minority carriers to form at the surface
- Capacitance looks like a parallel-plate capacitor

MOSCap Capacitance

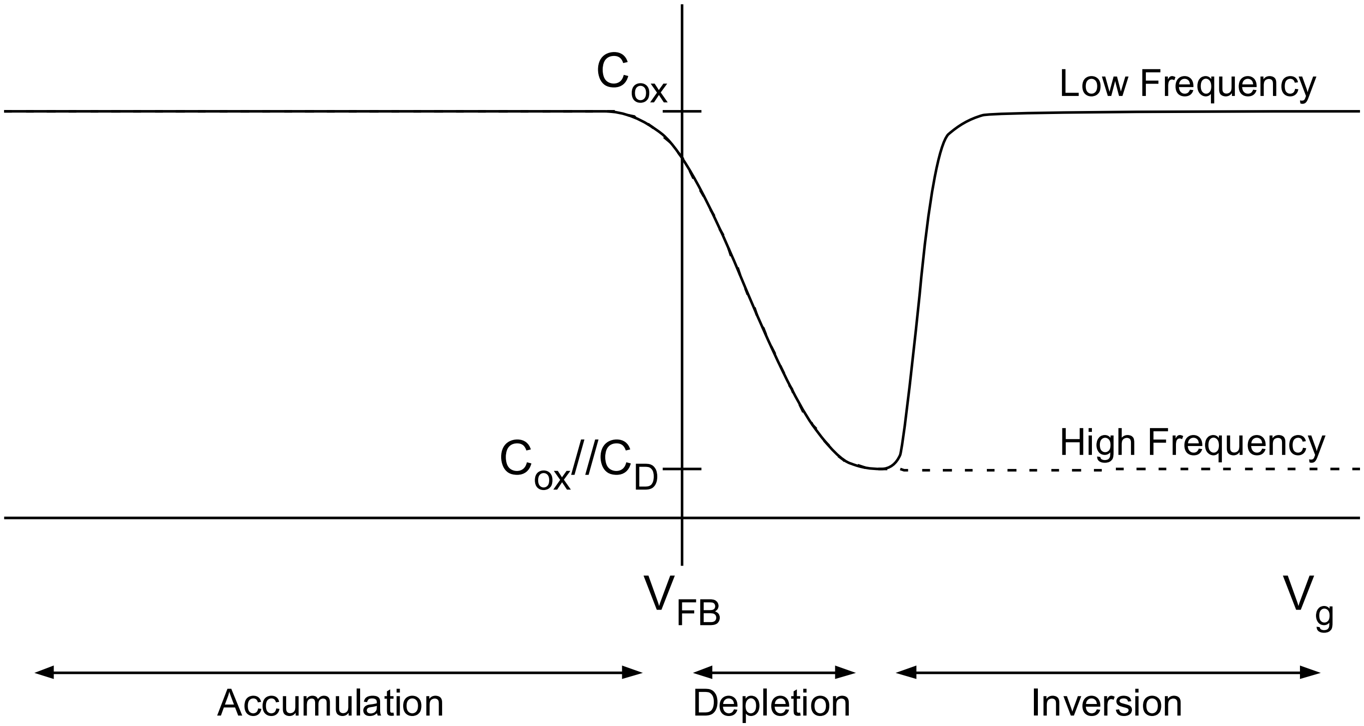


Inversion (High Frequency)

- At higher frequencies, there is no time for minority carriers to form at the surface
- Instead, more charge is formed by varying the width of the depletion region
- Total capacitance looks like two capacitors in series

$$C_T = C_{ox} // C_D$$

MOSCap Capacitance

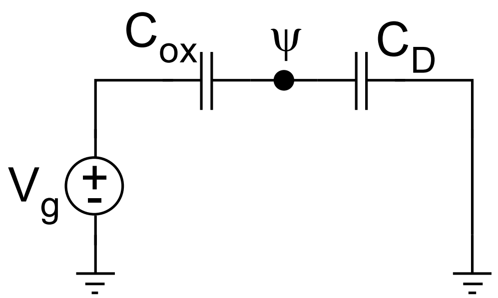


Capacitance in Depletion/Inversion

- Capacitance composed of two parts
  - Linear capacitor from gate to surface potential
    - C_{ox} (Oxide Capacitance)
  - Nonlinear capacitor from surface potential to substrate
    - C_D (Depletion Capacitance)

$$C_T = C_{ox} // C_D = \frac{C_{ox} C_D}{C_{ox} + C_D}$$

Surface Potential



$$\Delta\psi = \frac{C_{ox}}{C_{ox} + C_D}\Delta V_g$$

Let $\kappa = \frac{C_{ox}}{C_{ox} + C_D}$

- κ is often called the “subthreshold slope”
- Relatively constant in weak inversion
    - C_D is ~constant in weak inversion