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) \(\rightarrow\) Charge-Coupled Devices (CCD)
MOSCap Construction

- Polysilicon ("poly"), a conductor
- $\text{SiO}_2$, an insulator
- Semiconductor
Under Bias – Flat Band

Flat Band ($V_{FB}$)
- Some voltage that provides flat bands
- Simply used as a reference
- May not be known ahead of time

- Bands are flat
- SiO$_2$ provides large barrier ~3.04eV

$V_A = V_{FB}$
Accumulation

Apply Negative Voltage

- 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 SiO₂ interface to balance the e⁻ on the gate
- Acts as a linear capacitor (parallel plates)
- Majority carriers “accumulate” at the SiO₂ interface

VA<VFB

ψ = Surface Potential

e⁻ will not get close to the boundary (drift)
h⁺ will accumulate at the boundary (fall into the groove)
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 $\approx$ # of exposed ions
- Strong Inversion
  - # of minority carriers $>>$ # of exposed ions
MOSCap Capacitance

Accumulation
- $\Delta Q$ from the small-signal AC variations
- Looks like a linear, parallel-plate capacitor
MOSCap Capacitance

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

\[ Q \quad \Delta Q \quad W \quad -Q \quad -\Delta Q \]

\[ C_{ox} \quad C_D \]
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.

\[
C_T = C_{ox} \parallel C_D
\]
MOSCap Capacitance

- Accumulation
- Depletion
- Inversion

- Low Frequency
- High Frequency

\( C_{ox} \)

\( C_{ox}/C_D \)

\( V_{FB} \)

\( V_g \)
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 \( \kappa = \frac{C_{ox}}{C_{ox} + C_D} \)

- \( \kappa \) is often called the “subthreshold slope”
- Relatively constant in weak inversion
  - \( C_D \) is \( \sim \)constant in weak inversion