Lecture 12

- Last time:
  - pn junction *small-signal* capacitance
  - start MOS structure

- Today:
  - MOS charge storage
  - MOS capacitor
MOS Structure

D.C.

I_G = 0

Charge Storage Element
AC, Au, Mo, W.

What type of charge... in substrate.

p-type
\( \varepsilon_s = 11.7 \varepsilon_0 \)

n-type

Metal interconnect to bulk

Gate oxide
\( \varepsilon_{ox} = 3.9 \varepsilon_0 \)

45C

8T ±

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Thermal Equilibrium.

Charged bi-layer forms: + charges on gate, - in substrate

Built-in voltage between gate and substrate
Applying a DC Voltage $V_{GB}$

**Goal:** find out how the gate charge $Q_G$ varies as a function of the applied voltage $V_{GB}$.

$V_{GB} = 0$ V.

**Procedure:**

- (i) go negative until built-in charge is cancelled.
- (ii) keep going until charge on gate is negative.
- (iii) go positive from thermal equilibrium.
- (iv) keep increasing $V_{GB}$ until ...
Cancel the Built-in Voltage

Apply $V_{FB}$ to "zero" the built-in voltage

$V_{GB} = V_{FB}$

$V_{BE} = -0.2$  
$-0.3$

$V_{BE} < 0$

$V_{FB} = \text{"flat band" voltage}$
$= -0.9 \text{V}$

Thermal Equil. M

$R_x = \ldots 0$

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Accumulation

\[ V_{GB} < V_{FB} \quad (\approx -0.9 \text{ V}) \]

- DOPED WITH
  - p-type
  - n-type

- OPPOSITES ATTRACT:

\[ \rho(x) \]

\[ + \text{CHARGE \ldots holes! mobile,} \]

\[ Q_0 = C_{ox}(V_{GB} - V_{FB}) \]

\[ \text{true for} \quad V_{GB} < V_{FB} \]

\[ C = C_{ox} = \frac{E_{ox}}{t_{ox}} \approx \frac{4 \times 10^6}{11 \times 10^{-3}} \text{ C/V} \]
Depletion: \( V_{GB} > V_{FB} \)

\[ V_{FB} < V_{GB} < V_{Tn} \]

\[ Q_G = f(V_{gs}) \]

For \( V_{gs} > V_{FB} \)

\[ V_{gs} = 0, 0.5, 1, 1.5, 2, \ldots, 20 \text{V} \]

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Vertical $E$ field increases at the surface, lowering the barrier between the n-type region next to the gate and the channel underneath it... eventually (at $V_{\text{GB}} = V_{Tn}$), electrons flood in and the surface of the substrate has an inversion layer.
MOS Capacitor in Inversion

Increasing voltage → additional charge stored in inversion layer
Charge vs. Voltage Curve

- $Q_s (V_{GB})$
- $Q_B (V_{GB})$
- $V_{FB}$
- $V_{Tm}$
MOS Capacitance vs. Voltage

\[ V_{FB} = 0.6 \text{ V} \]

\[ V_{Tn} = 0.6 \text{ V} \]