Die Image

Rectangular MOSFETs: W/L (µm) = 20/2, 40/4, 100/10, 400/40, 600/60, 800/80, 1000/100
Circular MOSFETs: L = 6, 10, 40, 60, 80, 100 µm
N-Channel MOSFET Structures

Source
Gate
Drain

Channel

ILD
Poly-Si
P- Substrate

SEM – Cross-Section

MOSFET Characteristics

(n-MOSFET)

\[ C_{ox} = \frac{\varepsilon_{ox}}{d_{ox}} A \]

\[ I_{DS} \]

At \( V_{DS} \ll (V_{GS} - V_{T}) \)

\[ I_{DS} \approx \frac{W}{2T_{Hn}} C_{ox} (V_{GS} - V_{T}) V_{DS} \]
MOSFET Characteristics

Ideal MOSFET with Gradual Channel Approximation: \[ I_{DS} - V_{DS} \]

\[ I_{DS} = \frac{W}{L} \mu_{ns} C_{ox} \left\{ \left( V_{GS} - 2\psi_B - \frac{V_{DS}}{2} \right) V_{DS} - \frac{2}{3} \frac{\sqrt{2\varepsilon_s q N_A}}{C_{ox}} \left[ (V_{DS} + 2\psi_B) \frac{3}{2} - (2\psi_B)^{\frac{3}{2}} \right] \right\} \]

\[ \psi_B = \frac{kT}{q} \ln \frac{N_A}{n_i} \]

At low drain voltages (linear region):

\[ I_{DS} \approx \frac{W}{L} \mu_{ns} C_{ox} (V_{GS} - V_T) V_{DS} \]

\[ V_T = 2\psi_B + \frac{2\sqrt{\varepsilon_s q N_A \psi_B}}{C_{ox}} \]

At pinch-off and beyond (saturation region): Current Source

\[ I_{DS} = \frac{W}{2L} \mu_{ns} C_{ox} (V_{GS} - V_T)^2 \]

MOSFET Characteristics

Channel length modulation (after channel pinch-off):

\[ I_{DS} = \frac{W}{2(L - \Delta L)} \mu_{ns} C_{ox} (V_{GS} - V_T)^2 \]

\[ \approx \frac{W}{2L} \mu_{ns} C_{ox} (V_{GS} - V_T)^2 (1 + \lambda V_{DS}) \]

\[ \Delta L \approx \lambda V_{DS} \]
Basic Test Equipment Training

• Students need to know how to operate
  – Wafer probing station
    *(Never touch a wafer with bare hands!!)*
  – HP 4192 LCR Meter
  – Keithley 4200-SCS
    Semiconductor Characterization, or
  – System Sony/Tektronix 370A curve tracer, or
  HP 4145/4155 Parametric Analyzer

Probe Station & e-Testing

Karl-Suss Probe Station

Keithley 4200-SCS
e-Testing using Probe Station

Sheet resistance testing
Van Der Pauw Technique

Contact Resistance
Kelvin Contact Resistance

Transmission Line structure

Keithley 4200-SCS
Semiconductor Characterization System

ECSE-6300 IC Fabrication Laboratory
James J.-Q. Lu
Basic TEG Testing

• Determine the sheet resistance, $R_s$, of n+ source by measuring Van de Pauw structures
• Measure specific contact resistance, $R_c$, of Kelvin or transmission line structures to determine the adequacy of metal contacts to n+ source/drain regions
• Measure C-V on MOS capacitors or FETs to determine oxide thickness, $t_{ox}$, and flatband, $V_{FB}$, and/or threshold voltage, $V_T$
Basic MOSFET Testing

- Check for Gate to Source/Drain shorts
- Determine threshold voltage, $V_T$
  - Gate voltage at which $I_{DS} = 0$ and $V_{DS} = 0.1V$
  - Interpolate it from the $I_{DS}$ vs. $V_{GS}$ curve (Why?)
- Measure transconductance ($g_m$) and hence field-effect mobility ($\mu_{FE}$):
  
  $$g_m = \left. \frac{\partial I_{DS}}{\partial V_{GS}} \right|_{V_{DS}}$$

  In the linear region:
  $$g_m = (W/L)\mu_{FE}C_{ox}V_D$$
  $$\mu_{FE} = g_m / \left[ C_{ox} (W/L) V_D \right]$$

- Measure $g_m$ and $\mu_{FE}$ in the saturation region

MOSFET Testing

- Measure ON-resistance ($R_{on}$)
  $$R_{on} = \left. \frac{\partial I_{DS}}{\partial V_{DS}} \right|_{V_{GS}=5V}$$
  at $V_{DS} = 0.1$-$0.5V$

- Measure breakdown voltage ($B_{V_{DSS}}$)
  - Drain voltage (with the gate grounded) at which $I_{DS}$ increases rapidly, typical $I_{DS(max)} = 10\mu A$

- Assess the effect of substrate bias on $V_T$
- Determine the channel length modulation parameter $\lambda$
- Measure the subthreshold region parameters (e.g., subthreshold swing $S$)
MOSFET Testing

- Measure various capacitances
  - Gate capacitances ($C_{GSS}$, $C_{GSO}$, $C_{GDS}$, $C_{GDO}$)
- Measure switching characteristics
  - Turn-on and turn-off times ($t_{ON}$, $t_{OFF}$)
  - Gate charge during turn-on and turn-off
- Determine the dependence of basic device parameters on temperature

Data Analysis

- Assess threshold voltage value on processing and material parameters (e.g., gate oxide thickness, substrate doping)
- Determine the dependence of static performance data ($g_m$, $BV$) on device design (channel length, circular vs. linear geometry)
- Determine the dependence of dynamic performance data ($t_{on}$, $t_{off}$, $C_{GXX}$’s) on device design (channel length, circular vs. linear geometry)
- Compare with your simulation wherever possible
Guidelines for IC FabLab Report

- Cover with group names and responsibility
- Acknowledgement
- Abstract
- Chapter 1: Technical Background
  - Introduction
  - Device Physics
  - Process Considerations
  - Basic MOSFET Processing
  - Processing & Device Modeling – TSUPREM, MEDICI, Sentaurus
  - Device Characteristics & Testing Techniques
- Chapter 2: Processing Procedures
  - Detailed process flows with comments/suggestions
  - Inspection results with photos
- Chapter 3: Electrical Test Results and Discussions
  - I-V, C-V, Device variations, etc., with tables/plots
- Chapter 4: Summary & Conclusions
- References & Appendix

Guidelines for IC FabLab Final Report

- Data:
  - Statistics: accuracy, standard variation (σ), system errors
  - Analysis: comparison between theory and experimental results and between different devices;
  - Interpretation: theoretical understanding and explanation, linking to the processing and simulation
- Presentations:
  - Schematics (introduction, processing, testing)
  - Plots (Figures): right data groups and clear labels
  - Tables: process steps, critical data and comparison
  - Equations to show relationships
  - Images: devices, blocks, cross-sections, wafer, tools, test conditions, people, etc.
- Components:
  - Structures: Abstract/Summary/Conclusion, Introductions, Processing, Testing, Acknowledgement and References
  - Clear responsibility of each team member: writing, simulation, processing, testing and analysis