MOSCAP AC Characterization Report (Oxide Growth Time Variation)

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Device: MOS Capacitor (MOSCAP)

Measurement: AC capacitance vs gate voltage (C–V) at temperatures from **300 K to 400 K**, for four devices fabricated with different oxide thicknesses.

Figure: Attached plot titled "AC characteristics.png" (C(g,g) vs Vg for multiple devices with different oxide growth times).

Abstract

This report presents the AC C–V characterization of MOS capacitors simulated in Sentaurus TCAD. Four MOSCAPs were fabricated/simulated with different oxide thicknesses obtained by varying the **oxide growth time** during thermal oxidation. The AC capacitance was measured as a function of gate voltage over the temperature range 300 K–400 K. The aim is to investigate how varying oxide thickness influences the accumulation, depletion, and inversion capacitances, and to observe temperature-dependent variations in C–V characteristics.

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1. Device & Process Summary

- **Structure:** Metal–oxide–semiconductor capacitor (MOSCAP)
- **Oxide:** Thermal SiO_2, grown under identical temperature but **different oxidation times**, resulting in different oxide thicknesses for each of the four devices.
- **Oxide thickness (t_ox):** Varies with oxidation time; longer oxidation time yields thicker oxide and hence lower oxide capacitance ($Cox \propto 1/t_{ox}$).
- **Substrate:** p-type (or n-type) silicon with uniform doping concentration.
- **Gate electrode:** Ideal metal gate.
- **Process steps:** Implemented using sprocess — oxidation (time varied), implant/diffusion (for substrate doping), and metallization.

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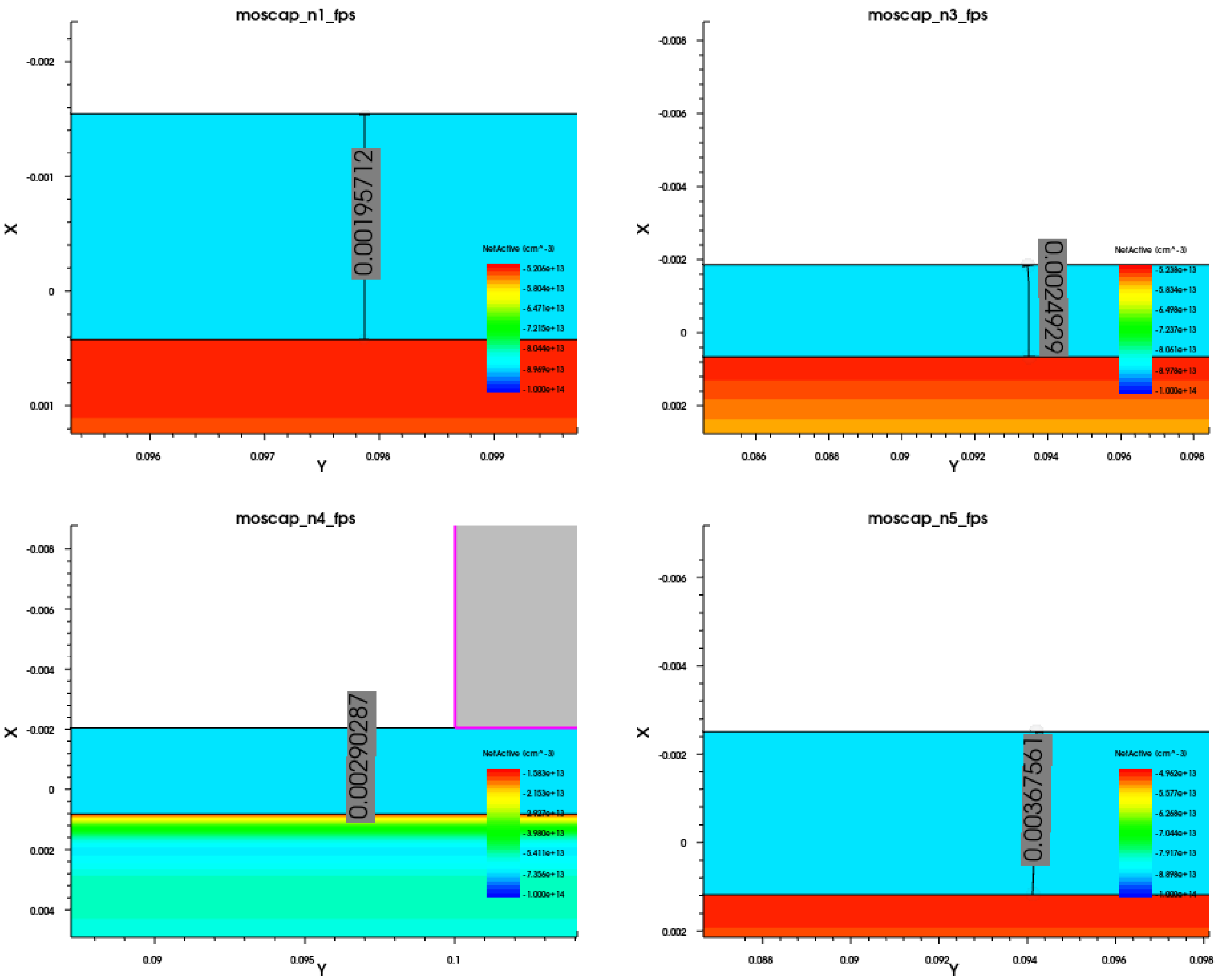
2. Simulation Setup

- **Tool:** Synopsys Sentaurus TCAD
- **Analysis type:** Small-signal AC (capacitance extraction)
- **Parameter sweep:** Gate voltage (Vg) swept from –3 V to +3 V
- **Temperature range:** 300 K – 400 K
- **AC frequency:** (To be provided; typically 1 MHz or 100 kHz)
- **Variation:** Oxide thickness controlled via oxidation time (4 different values)
- **Bias conditions:** Gate voltage swept; substrate grounded.



The above plot shows the variation in oxide thickness when the diffusion time is varied.

SPROCESS code for structure generation-

```
math coord.ucs
line x location= 0.0 spacing= 1.0<nm> tag= SiTop
line x location= 50.0<nm> spacing= 1.0<nm>
line x location= 0.5<um> spacing= 50.0<nm> tag= SiBottom
line y location= 0.0 spacing= 1.0<nm> tag= Mid
line y location= 0.40<um> spacing= 1.0<nm> tag= Right
region Silicon xlo= SiTop xhi= SiBottom ylo= Mid yhi= Right
init concentration= 1e14<cm-3> field= Boron
AdvancedCalibration
pdbSet Grid NativeLayerThickness 1e-7
pdbSet Oxide Grid perp.add.dist 1e-7
diffuse temperature= 850<C> time= @time_o@<min> O2
deposit material= {Aluminum} type= isotropic time= 1 rate= {0.03}
mask name= contacts_mask left= 0.1<um> right= 0.3<um>
etch material= {Aluminum} type= anisotropic time= 1 rate= {0.25} mask= contacts_mask
contact name="body" bottom Silicon
contact name="gate" box Aluminum xlo=-0.04 xhi=0 ylo= 0 yhi= 0.4
struct tdr = moscap_n@node@
exit
```

To receive the capacitance plot we have to enter the following code in sdevice-

```
# Temperature Range: 300 K – 400 K (to be varied externally)
##################################################################

Device "MOS" {
  ##############################################################
  # 1. File and Output Setup
  ##############################################################
  File {
    Grid     = "moscap_fps.tdr"     # Mesh structure file from sprocess
    Plot     = "moscap_N"           # Output plot prefix
    Parameter= "moscap_N"           # Optional parameter set name
    Current  = "moscap"             # Current data output
  }

  ##############################################################
  # 2. Electrical Contacts (Electrodes)
  ##############################################################
  Electrode {
    { Name = "gate" Voltage = 0.0 }
    { Name = "body" Voltage = 0.0 }
  }

  ##############################################################
  # 3. Physical Models
  ##############################################################
  Physics {
    Fermi                          # Enables Fermi–Dirac statistics
    EffectiveIntrinsicDensity( OldSlotboom ) # Improved carrier statistics

    Mobility(                      # Carrier mobility models
      DopingDep                    # Doping-dependent mobility
```

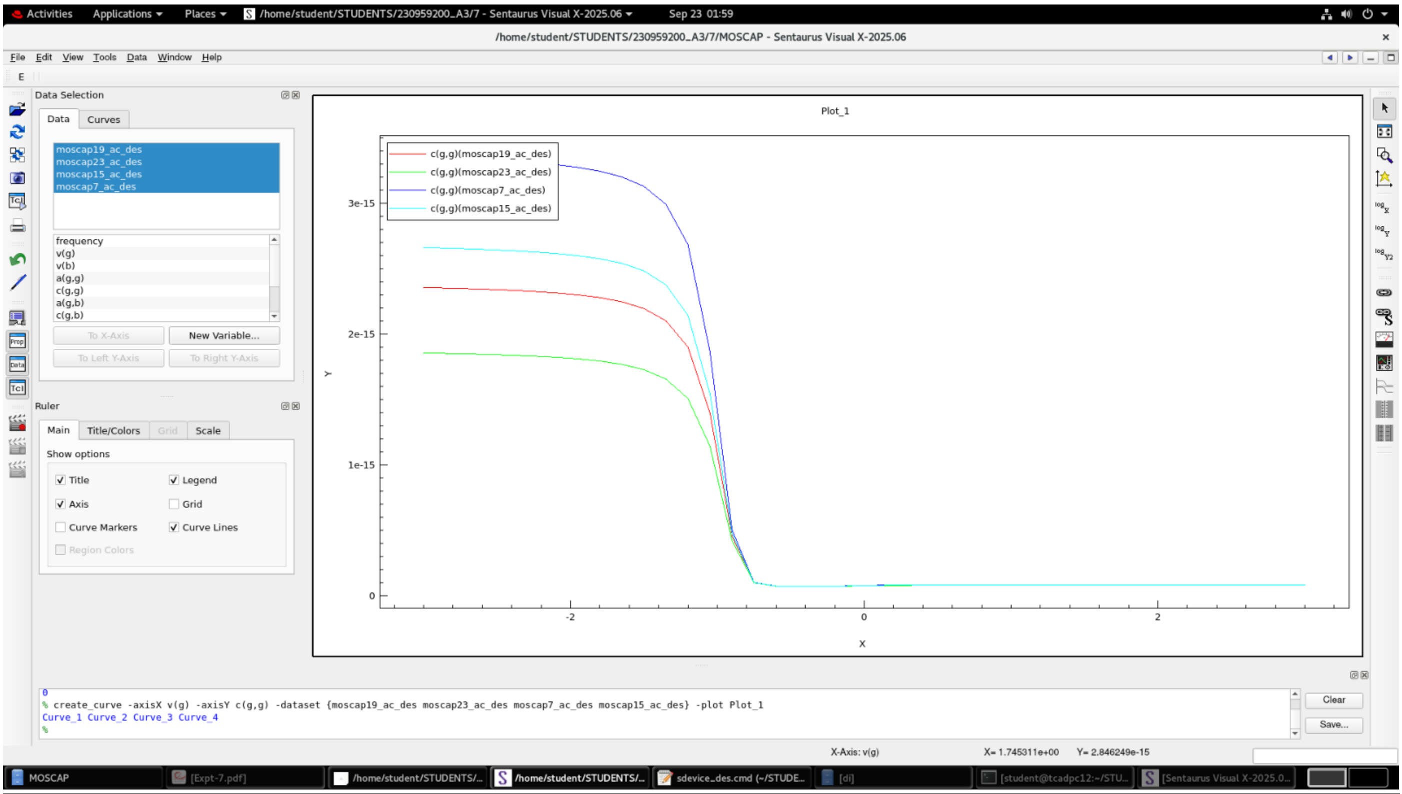
```
    eHighFieldsaturation( GradQuasiFermi )  # Electron high-field saturation
    hHighFieldsaturation( GradQuasiFermi )  # Hole high-field saturation
    Enormal                   # Normal electric field dependence
  )

  Recombination(                  # Carrier recombination models
    SRH( DopingDep TempDependence ) # Shockley–Read–Hall with T dependence
  )
}

################################################################
# 4. Quantities to be Plotted (Results to extract)
################################################################
Plot {
  # Carrier densities and currents
  eDensity hDensity
  TotalCurrent/Vector eCurrent/Vector hCurrent/Vector
  eMobility hMobility
  eVelocity hVelocity
  eQuasiFermi hQuasiFermi

  # Temperature fields
  eTemperature Temperature hTemperature

  # Electric fields and potential
  ElectricField/Vector Potential SpaceCharge

  # Doping information
  Doping DonorConcentration AcceptorConcentration

  # Recombination and generation
  SRH Band2BandGeneration Auger
  ImpactIonization eImpactIonization hImpactIonization
```

```
   # Driving forces
   eGradQuasiFermi/Vector hGradQuasiFermi/Vector
   eEparallel hEparallel eENormal hENormal

   # Band structure information
   BandGap BandGapNarrowing Affinity
   ConductionBand ValenceBand eQuantumPotential
}

#################################################################
# 5. Numerical Solver Settings
#################################################################
Math {
   RelErrControl
   Digits = 5
   ErrRef(electron) = 1.e10
   ErrRef(hole)     = 1.e10
   Iterations = 20
   Notdamped = 100
   Method = Blocked
   SubMethod = Super
   ACMethod = Blocked
   ACSubMethod = Super
}

#################################################################
# 6. Output File Names
#################################################################
File {
   Output   = "moscap@node@"         # DC and AC data output prefix
   ACExtract = "moscap@node@"        # AC extraction results
}

#################################################################
```

```
# 7. Circuit Connections (System Definition)
#################################################################
System {
   # Physical device instance
   MOS nmos1 ( "body" = b "gate" = g )

   # External voltage sources
   Vsource_pset vb (b 0) { dc = 0.0 }   # Body bias (grounded)
   Vsource_pset vg (g 0) { dc = 0.0 }   # Gate bias (swept)
}

#################################################################
# 8. Solution Sequence
#################################################################
Solve {

   # Step 1 — Initial potential solution
   NewCurrentPrefix = "init_"
   Coupled(Iterations = 100) { Poisson }

   # Step 2 — Equilibrium (DC bias)
   Coupled { Poisson Electron Hole }

   # Step 3 — DC sweep (Vg from 0 → -3 V)
   Quasistationary (
      InitialStep = 0.1
      Increment   = 1.3
      MaxStep     = 0.5
      MinStep     = 1.e-5
      Goal { Parameter = vg.dc Voltage = -3.0 }
   ) {
      Coupled { Poisson Electron Hole }
   }
```

```
    # Step 4 — AC Analysis (Vg from -3 V → +3 V)
    NewCurrentPrefix = ""
    Quasistationary (
      InitialStep = 0.01
      Increment   = 1.3
      MaxStep     = 0.05
      MinStep     = 1.e-5
      Goal { Parameter = vg.dc Voltage = 3.0 }
    ) {
      ACCoupled (
        StartFrequency = 1E6        # 1 MHz AC frequency
        EndFrequency   = 1E6
        NumberOfPoints = 1
        Decade
        Node(g b)                   # Capacitance between gate and body
        Exclude(vg vb)
        ACCompute (Time = (Range = (0 1) Intervals = 40))
      ) {
        Poisson Electron Hole
      }
    }
  }
}
######################################################################
# End of File
```

<u>Output plot-</u>



Interpretation

- **Oxide thickness effect:** The vertical separation of C–V curves corresponds to the expected difference in oxide capacitance values caused by different oxidation times.
- **Temperature effect:** Minor lateral or vertical shifts may arise from semiconductor intrinsic property changes with temperature.
- **Frequency consideration:** At high AC frequencies, inversion capacitance remains low; if low-frequency data is used, inversion capacitance can increase due to minority carrier response.

Conclusions-

- Varying oxidation time successfully produced MOS capacitors with different oxide thicknesses, confirmed through varying accumulation capacitance values.
- The accumulation capacitance decreases as oxide thickness increases ($C \propto 1/t_{ox}$).
- Temperature variation between 300–400 K introduces small but noticeable changes in C–V characteristics, mainly due to intrinsic carrier and bandgap effects.
- The simulation agrees with theoretical expectations for MOS capacitors with varying oxide thickness.