Challenges and Solutions in Modeling and Simulation of Device Self-heating, Reliability Aging and Statistical Variability Effects

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Outline

• Device aging, self-heating effects and impacts

• Challenges in circuit simulation and design verification

• SNPS solutions

• Summary
MOS Reliability is a Growing Concern

- More severely impact on design in advanced nodes
- Must be addressed at design stage prior to production
Reliability Aging in Automotive Applications

- **Automotive electronics**: Would you accept 10% probability for your car to break down?
- **Connected devices**: Shipments will top 2 billion units in 2015 → need for low failure rate

**Total failure probability = 10%**

**Aging Analysis** is a way of modeling and predicting the failure modes and mean time to failure of complex systems.
Device Self-Heating in Advanced Technology Nodes

• FINFET
  – Better gate control, Short-channel effect, more conducting area per footprint
  – Difficult to transfer Heat to substrate

• FDSOI
  – Better gate control with planner structure, Vt modulation
  – Difficult to transfer Heat to substrate due to oxide

[TSMC OIP 2015]

A. Majumdar, “Microscale Heat Conduction in Dielectric Thin Films,” Journal of Heat Transfer,
Device Self-heating Effect Impact Analog/RF Designs

Figure 4. Self-heating effect on $g_{ds}$, between about 0.2 and 20 MHz or even larger, the AC self-heating effect gradually disappears because it cannot follow the rapid signal change and the $g_{ds}$ increase to the AC-heating free value.


Figure 4.6. An eye diagram representation of the output signal from a digital circuit suffering from self-heating-induced ISI. The input to the circuit in this example had been sitting in a low state for a long time (relative to the thermal time constant), and then began switching with a 50% duty cycle. The input signal risetime of 100 psec results in ~15 psec of self-heating-induced ISI.
Holistic Requirements for Simulation-based Failure Rate Analysis

Method
- Large-volume sample
- Stress in Time
- Circuit performance degradation

Needs
- Large-sample capability
- Block variation
- Aging
- Self-heating

Solution
- HSPICE
  - FineSim
  - CustomSim
SPICE Model Requirements Beyond Compact Model

• LDE and Statistical

• Self-heating
  – Local heat during current flow
  – Confined structure
  – Scaling and power density exacerbate the effect
  – Interact with device aging

• Device Aging: HCI, BTI, TDDB
  – Scaling exacerbate HCI
  – Interaction of SHE
  – Scaling drive more concerns in TDDB
Efficient Self-heating Simulation in HSPICE

- FinFET, FDSOI devices see stronger self-heating effect. Foundry SPICE model turns on SHE model component. Performance and convergence impact

- HSPICE efficient SHE solution
  - No accuracy loss
  - Close to run time w.r.t non-SHE
Comprehensive Device Aging Analysis (MOSRA)

HSPICE, FineSim SPICE, CustomSim

- Aging simulation with built-in models, BTI, HCI, TDDB
- Aging-aware variation analysis
- Foundry certified for FinFET & Automotive grade flow

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“Fresh” simulation
Stress computation
Post-stress simulation
Monte Carlo simulation
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Custom Compiler Environment

- Comprehensive setup, run for BTI, HCI, TDDB
- Detailed results of degradation effects
- Analyze results with Custom WaveView

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Result browser
Cross-probe to Custom WaveView
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Degradation due to Device Aging
Efficient Monte Carlo Solution

Failure rate estimation requires one million+ or more Monte Carlo samples

Industry adoption

“This technology is very useful and it will be used extensively …”

Sigma Amplification: 100 simulations with 2x amplification factor match well with 100M simulated!
Self-heating and Variation Aware MOSRA

- MOSRA is a 2-step simulation: 1) Age computation, 2) Post-age analysis
- Process variability impact need to be considered in both step simulations for accuracy

Flow-1
Age Calc: Age w/o process variation
Post-age: process variation
CPU cost: N+1

Flow-2
Age Calc: Age w/ process variation
Post-age: Age variation + process variation
CPU cost: 2N
Simulation-based Failure Rate Analysis Flow

- **Circuit Worst-case Sensitivity Analysis (Simulator)**
  - Self-heating Simulation (Simulator)
  - Aging Simulation (Simulator)
  - Large-sample Monte-Carlo
  - Evaluate Failures
  - Estimate Failure Rate

- **Worst-case sensitivity analysis**
  - find highest contributors to circuit degradation

- **Self-heating simulation**

- **Aging simulation**
  - creating the degraded (aged) models
  - stress the degraded devices

- **Large-sample Monte-Carlo**
  - random variations on degraded circuit yield parametric or functional failures contributing to the random failure rate

- **Estimate failure rate**
  - cycle back as required by mission profile
Comprehensive Tool Set and Features

ISO 26262 Certified

Robust Design

- HSPICE
  - High-Sigma Analysis
- FineSim SPICE
  - Smart Corner Simulation
- CustomSim
  - High Cap. Monte Carlo
- Monte Carlo
- Aging
- Safe Operating Area
- Corners
- EM / IR
- Mixed-signal

Custom Compiler Environment

- Design Outliers
- Violation Contributor
Summary

• Device aging and self-heating effects are important in advanced technology nodes and automotive applications

• Simulation based reliability and failure rate analysis impose holistic requirements and challenges to circuit simulation

• Synopsys provides comprehensive solutions considering accuracy and turnaround time
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