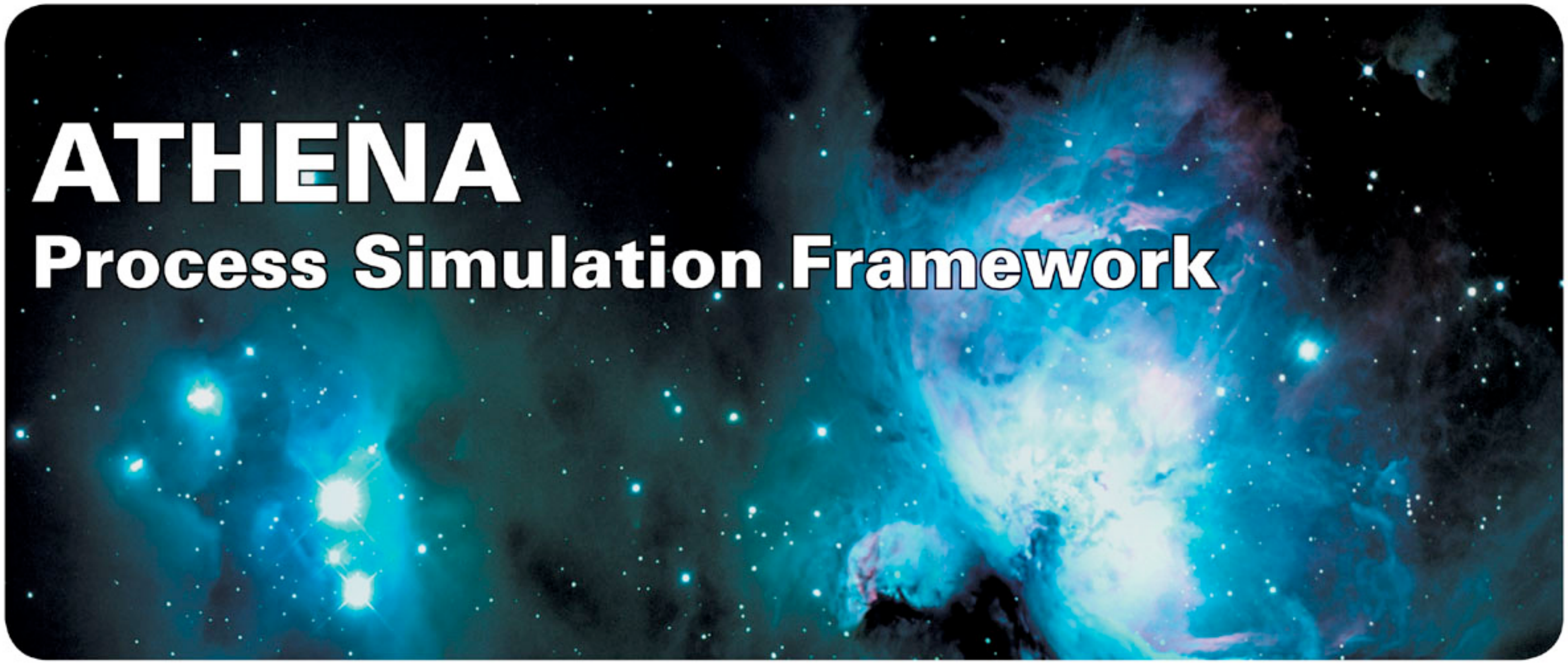
Process Simulation Calibration



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Agenda

- Two levels of Process Simulation Calibration
- Sources of Errors in Process Simulation
- Model Selection
- Calibration of Different Processes
- Using Optimizer
- Overview of VWF-based calibration
- Practical examples

Two Levels of Process Simulation Calibration

- Process calibration is the most important issue in TCAD today
- Some reasons why process simulation is far from ideal:
  - Some physics is poorly characterized even for standard processes: segregation,defect generation etc.
  - Models for many processes are still in a development stage: silicidation, dislocation loops, cluster formation, details of implant channeling etc.
  - Characterization of processes in non-silicon materials is lagging far behind
  - Many processes(e.g. deposition, etching) depend on equipment

Two Levels of Process Simulation Calibration (cont)

- Silvaco provides tools to perform calibration on two levels.
- The first (local) level of calibration allows to tune one or several parameters of a specific model for a specific process step
- The tools and features used for the first level are DeckBuild, Optimizer, Extract, and Autointerface
- The second (global) level of calibration allows to calibrate many parameters of several key models for the whole process
- The second level of calibration uses VWF Automation and Production Tools

Sources of Errors in Process Simulation

- Insufficient physical models:
  - Amorphization/recrystallization effects
  - Cascades in implant
  - Dislocation loops and cluster effects
  - Stress generation
- Unknown or inaccurate material parameters
  - For non-silicon materials, almost all parameters are subject of calibration
  - For physically based deposition and etching almost all rate parameters are equipment-dependent and needed to be calibrated

Sources of Errors in Process Simulation (cont)

- Inaccurate coefficients of physically based models
- Most of parameters of physically based models cannot be measured directly and practically impossible to derive from first principles, e.g.
  - Local electronic stopping for MC ion implantation
  - Diffusivities, generation and recombination rates for point defects for advanced diffusion models
  - Oxidation rate decrease in presence of stresses
  - Segregation coefficients
- Use of empirical models
- Numeric/mesh induced errors

Model Selection

- Implant Models
  - Default is Pearson (or double Pearson), range parameters can be set in the IMPLANT or MOMENT statement
  - Amorphous Monte Carlo could be useful for multilayered structures, high angled implants, shadowing effects
  - Crystalline Monte Carlo is for implants with high channeling probability or to predict a dose dependency
- Oxidation Models
  - COMPRESS is default, good for almost all cases
  - Stress-dependent VISCOUS is recommended for LOCOSes with thick nitride layer and trench corner effects

Model Selection (cont)

- Diffusion Models
    - FERMI is default, good for low concentration, no or little oxidation/ silicidation
    - TWO.DIM is for Oxidation/Silicidation Enhanced Diffusion
    - FULL.CPL and its enhancements is for high concentration and co-diffusion effects, transient-enhanced diffusion, RTA

Implant Calibration

- Needed in the case of a short subsequent diffusion
- Could be accurately done only if as-implanted SIMS profiles are available
- Only depth profiles could be calibrated
- Values of moments (range, std.dev, gamma, etc) in the MOMENTS or IMPLANT statement should be used

Oxidation Calibration

- Use thin oxide enhancement coefficients for short oxidations (Tox <~ 0.05 micron). This is extremely important for case of low-temperature wet oxidation:
  - oxide silicon wet orient=100 thinox.0=6.57e6 ....
- Use different rates for polysilicon
- COMPRESS model can be tuned with nitride Young's modules
  - material nitride Young.m=1e.e14
- VISCOUS stress-dependent model can be tuned with nitride and oxide viscosities:
  - material nitride visc.0=5.0e12
- And/or stress-induced reduction factors:
  - oxide Vd=25 Vc=300 Vr=30

Diffusion Calibration

- Diffusion coefficient tuning for FERMI model is the last resort for silicon. More commonly required for other materials:
  - arsenic oxide Dix.0=1.75 Dix.E=4.89
- Use interstitial injection coefficient theta.0 for tuning OED effect in the TWO.DIM model
  - interstitial silicon /oxide theta.0=3.67e-5
- Use implant DAM.FACTOR parameter to tune implant damage enhanced diffusion with TWO.DIM or FULL.CPL model
  - implant arsenic energy=50 dose=5e15 unit.dam dam.fac=0.01
- Use surface and/or bulk interstitial/vacancy recombination coefficients to tune TED (RTA) processes with FULL.CPL model

Diffusion Calibration - Impurity Segregation

- Controlled by segregation and transport terms
- Segregation determines equilibrium ratio of impurity concentration in two materials
- Transport determines rate at which the equilibrium is reached
- Different effects during oxidizing and inert anneals
- Can be tuned using:
  - boron silicon /oxide Seg.0=1126 Seg.E=0.91 Trn.0=1.66e-7 Trn.E=0.0

Diffusion Calibration - Activation/Clustering

- Important for high concentration diffusion (Emitters and S/D)
- In the current version clustering model is valid only for Arsenic
- Solid Solubility model is valid for all other impurities
- Clustered impurity or portion of impurity above Solid Solubility limit is assumed immobile during diffusion
- Can be calibrated using:
  - arsenic silicon Ctn.0=5.19e-23 Ctn.E=0.60

Calibration Using Optimizer

- Use 1D mode for implant or diffusion calibration
- Select parameters to tune and insert statements with these parameters into input deck
- Select target parameters (oxide thickness, pn-junction, sheet resistance, Vt, etc.) and insert corresponding EXTRACT statements into the input deck
- Select OPTIMIZER from DeckBuild's Main Control Menu
- Set RMS, Average, and Maximum errors
- Edit-Add parameters from highlighted statements with selected parameters
- Set reasonable Min and Max values
- Edit-Add targets by highlighting the EXTRACT statements
- Run Optimizer by selecting Optimize button

Calibration Using VWF

- Obviously local calibration could be accurate only within very narrow limits of process conditions
- Multi-dimensional multi-variant calibration is needed while only limited set of experimental data is available
- VWF calibration methodology could be applied to two distinct types of calibration tasks
- First is multi-parametric calibration of a certain process step, e.g.:
  - Shape and size of LOCOS Bird’s Beak for different temperatures, ambient conditions, nitride thicknesses, etc.
- Second is calibration of the whole technological process from bare silicon until complete device characteristics

Calibration Using VWF (cont)

- Calibrate in 4 basic steps:
  1. Point (Local) calibrate to generate a baseline with VWF Interactive Tools
  2. Perform Sensitivity Analysis with VWF Automation Tools
  3. Generate Virtual Split lot data with VWF Automation Tools
  4. Perform Multi-Target Multi-Dimensional Response Surface Model (RSM) Calibration with VWF Production Tools
- The first step is already discussed in details

Calibration Using VWF - Sensitivity Analysis

- To perform Sensitivity Analysis:
- Add all Design parameter Targets with Deckbuild’s ‘extract’ statements
  - Bird’s Beak Length, oxide thicknesses add different sections, oxide thinning factor (LOCOS case), or
  - Toxs, Sheet Resistance, Vts, Theta, Beta, etc (whole process case)
- Split on a Large Number of Parameters
  - All Major Processing Parameters (Temperatures, Doses, Energies, Thicknesses, CDs)
  - All Major Calibration Parameters /Physical Model Coefficients (many of them are mentioned above)

Calibration Using VWF - Sensitivity Analysis (cont)

- Sensitivity Analysis will generate an automated report indicating the Most Sensitive Parameters from the complete chosen list
- Decide upon Most Important Processing Parameters, say the top 3 to 10 of them
- Decide upon most Important Calibration Parameters, say the top 3 or 10 of them
  - These numbers depend upon available computer power

Calibration Using VWF - Virtual Split Lot

- Using VWF Automation Tools Generate an Design of Experiments (DOE) employing the Most Practical and the Most Important Process Parameters AND the Most Important Calibration Parameters
- Split lots may be Orthogonal DOE’s or Random DOE’s
- Run the Simulation Split Lot in Parallel on MP machine
- Generate RSM for each Design Parameter
- Type in the Nominal Measured Values to correct the RSM’s in the Nominal case alone
- Decide upon Silicon Split Lot’s Processing Parameter Corners
  - Decision based upon the confidence in the slope ONLY of the RSM’s
- Use VWF to generate a Real Split Lot and run wafers

Calibration Using VWF - RSM Fitting

- Condition (Filter and Average) Silicon measured data
- Create a simple split table file for the calibration target
  - Include limits, within this target file, to define calibration accuracy
- Load the (Calibration Parameters + Processing Parameters) RSM’s into VWF Production Tools
- Load in the Measured, Filtered and Averaged Data into Production Tools
- Production Tools will find values of Calibration Parameters that will best fit the Measured Data

Calibration Using VWF - RSM Fitting (cont)

- Adjust the RSM's to use fixed values of Calibration Parameters
- Input the measured Nominal case measured values to correct the RSM's in the Nominal Case
- A number of Predictive RSM's have been created for a given process
- Archive these RSM's for later non-expert usage with Production Tools
  - Yield Improvement
  - Failure analysis
- Update the Calibration Coefficients for future use in future baseline input decks