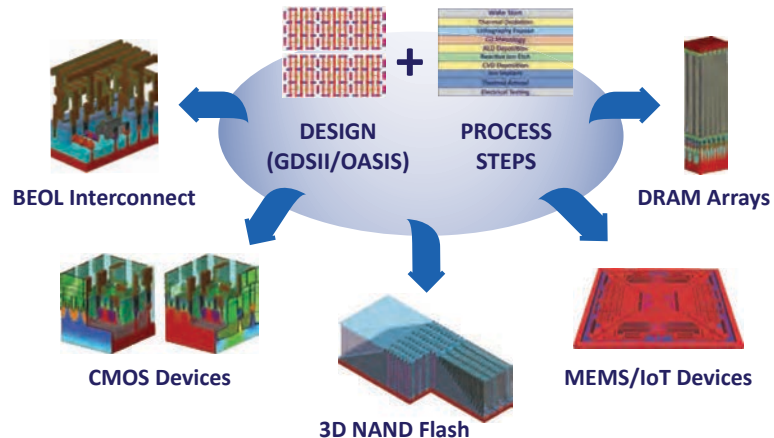# SEMulator3D ®
Predictive Process Modeling for Advanced Semiconductor Technologies

Addressing the Challenges of Advanced Semiconductor Fabrication

SEMulator3D enables companies to bring new technologies to volume production sooner. Continued semiconductor technology advancement into 3D processes, including FinFET, 3D Memory, and BEOL patterning, has significantly increased the complexity of process development. As a result, the traditional build-and-test approach to technology development has become excessively costly and time-consuming. Predictive 3D process modeling with Coventor's SEMulator3D virtual fabrication platform reduces development cycle time and costs associated with traditional silicon experimental learning.

Predict 3D Integrated Structure from Design and Process Data

DESIGN (GDSII/OASIS) + PROCESS STEPS

BEOL Interconnect

DRAM Arrays

CMOS Devices

MEMS/IoT Devices

3D NAND Flash

Accelerating Semiconductor Product Development using Virtual Fabrication

By offering an unprecedented combination of speed, capacity and accuracy, SEMulator3D is uniquely capable of modeling complex integrated process flows across large silicon areas. Utilizing the SEMulator3D virtual fabrication platform, engineering teams can efficiently develop process flows and perform automated virtual experiments.

Use Virtual Fabrication

- Decrease costly, time-consuming silicon learning cycles
- Identify process problems before fabrication
- Perform variation experiments not feasible in the actual fab
- Leverage virtual fabrication at every stage of technology development
- Flexible platform for multiple use cases and applications
- Applicable to any process and any layout, regardless of complexity or technology
- Predicts complex interactions between designs and integrated process flows

COVENTOR

SEMulator3D Mimics the Actual Fab (but is faster & lower cost)

Unlike actual wafer runs which take weeks to months, virtual fabrication takes minutes or hours to produce results. Starting from a virtual silicon wafer, it performs a series of unit processes (some requiring masks) to produce complex 3D structures. Just as in an actual fab, upstream unit process parameters (such as deposition conformality, etch anisotropy, selectivity, etc.) interact with other processes and design data in a complex way to impact the completed structure. The implications of process integration in terms of critical dimensions and other structural measurements can be easily visualized and quantified without the time and expense of actual wafer runs.
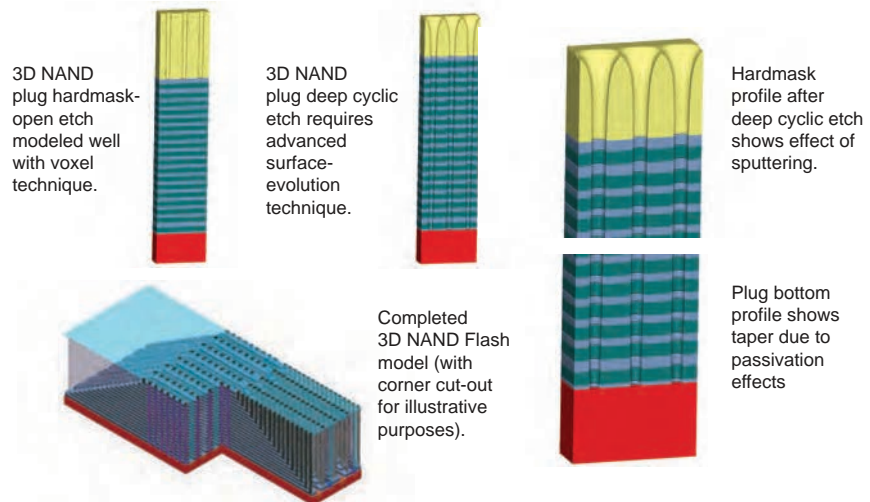
Actual Wafer Run vs. Virtual Fabrication
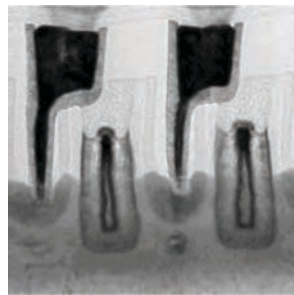
[Auth, et. al.; VLSI 2012]
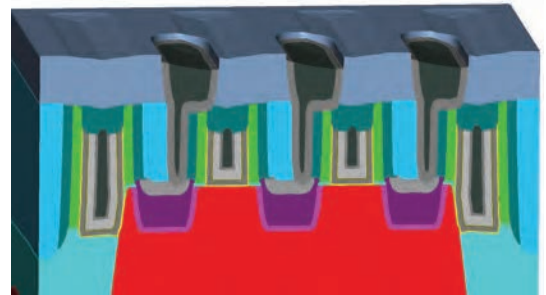
Solving Today's Process Integration Challenges

Challenges in current semiconductor processing extend beyond the single-device areas typically analyzed in the past. Traditional process modeling methods are limited to individual devices due to modeling performance limitations. SEMulator3D seamlessly switches between two sophisticated modeling methods: Voxel Modeling, a fast, robust, digital approach, and Surface Evolution, an analog approach capable of modeling a wide range of physical process behavior with great accuracy. This unique technology enables SEMulator3D to quickly solve today's most advanced process problems.
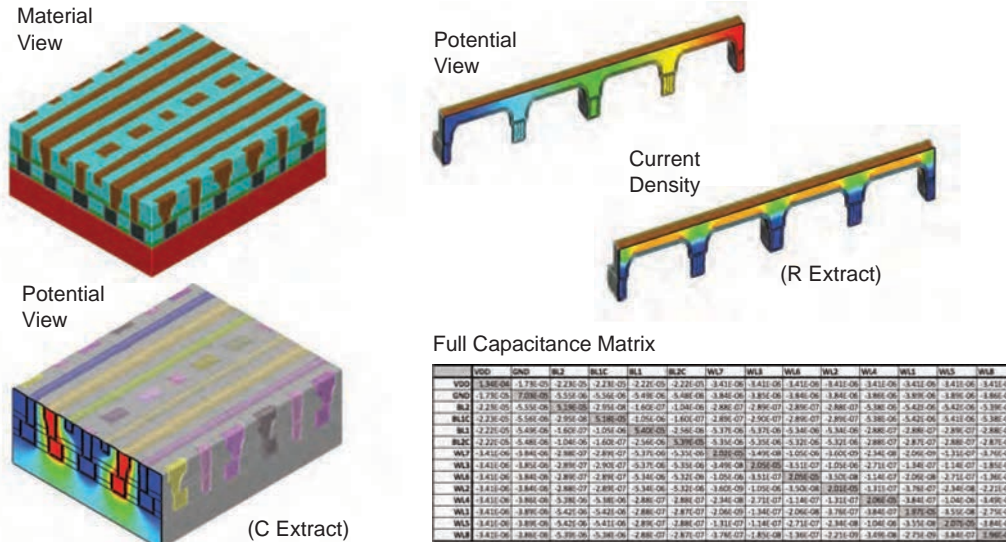
Advanced 3D NAND Process Modeling in SEMulator3D

3D NAND plug hardmask-open etch modeled well with voxel technique.

3D NAND plug deep cyclic etch requires advanced surface-evolution technique.

Hardmask profile after deep cyclic etch shows effect of sputtering.

Completed 3D NAND Flash model (with corner cut-out for illustrative purposes).

Plug bottom profile shows taper due to passivation effects

Quantify Critical Process Effects

SEMulator3D offers much more than 3D visualization – it provides quantitative analyses of the complex 3D models it generates. **Virtual Metrology, Structure Search, Design-Technology Checking** and **Profile Export** each offers unique capabilities for measuring, checking and analyzing device structures for quantitative results. New in SEMulator3D 6.0, the **Electrical Analysis** module adds powerful resistance and capacitance extraction to deepen the understanding of process and design sensitivities. These analysis capabilities, together with the **Expeditor** batch execution engine, enable massive parallel quantitative studies of process or design variation, enabling process assumption validation, design rule generation and yield ramp.

BEOL Interconnect R/C Extraction

Material View

Potential View

Potential View

(C Extract)

Potential View

Current Density

(R Extract)

Full Capacitance Matrix

Valuable at Every Stage of Technology Development

The World's Top Semiconductor and MEMS Companies use the SEMulator3D platform for:

• **Process Exploration –** Test processes not yet ready in the fab for integration impacts

• **Design Rule Validation –** Check untested designs for yield-limiting process sensitivities

• **Process Margin Analysis –** Identify process windows, and determine inline specifications

• **Device Design –** Export 3D models to FEA/BEA solvers for additional analysis

• **Yield Optimization –** Separate multi-process cross-wafer uniformity effects and optimize

• **Defect Analysis –** Study and prioritize defect evolution modes through subsequent process

• **Documentation & Visualization –** Create predictive 3D documentation for complex flows

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VIRTUAL METROLOGY
Extracts similar measurement data to actual, in-fab metrology.

STRUCTURE SEARCH
Analyzes the entire 3D model area for process sensitivities and design violations.

DESIGN-TECHNOLOGY CHECKING
Bridges the gap between 2D design rules and 3D structural constraints.

EXPEDITOR
Automates the execution of a large number of experiments in parallel to predict process or design variation effects.

PROFILE EXPORT
Extracts surface profiles (like in-fab AFM) or dopant profiles (like in-fab SIMS) to review detailed process features.

SEMulator3D Software Platform

Coventor offers several different software configurations to meet the diverse needs of the Semiconductor and MEMS industries. The SEMulator3D Basic Module is the basis of the software platform. The full Virtual Fabrication Software Bundle is comprised of three modules: Basic, Advanced Modeling and Automation. Additional software modules including Electrical Analysis, Advanced Design, 3D-Export and 3D-Reader are available to meet the needs of the most advanced applications.

	SEMulator3D Element	Contents	Overview

Virtual Fabrication Bundle	Basic	• Core Modeling Capabilities:
		  - Process Editor
		    * Default Step Library
		    * Custom Python Library
		    * Default Material Database
		  - Layout Editor (GDS compatible)
		  - 3D Voxel Modeling Engine
		  - 3D Model Viewer
		  - Direct Voxel-Data Export
		    * Direct interface to other software
			Package contains everything necessary to simulate and view complex CMOS process flows using the voxel modeling engine.

	Advanced Modeling	• 3D Surface Evolution Modeling Engine:
		  - MultiEtch Process
		  - Selective Epitaxy Process
		  - Crystal Plane-Dependent Etch
		  - Pattern-Dependent Etch
		  - Visibility-Limited Deposition/Etch
		  - Directed Self Assembly
		• Dopant Concentration Handling:
		  - Ion Implant
		  - Thermal Diffusion
		  - Doped Epitaxy
		  - Doped Deposition
		  - Gradient Visualization
			More accurate physics-driven process models for advanced processes.

	Automation	• Expeditor Batch Execution Engine • Analysis Editor (all new in 6.0) • Virtual Metrology • Structure Search • Design - Technology Checking • Profile Export (Dopant/Surface)	Automate large number of experiments and use metrology to measure critical geometry. Structure Search inspects entire build area for design/process violations.
Additional Modules	Electrical Analysis (all new in 6.0)	• Resistance Solver • Capacitance Solver • Port/Net Assignment	Calculate resistance of conductor nets and capacitance between nets directly within SEMulator3D.
	Advanced Design	• Layout Expert Tool	Viewing, cropping and merging of large GDS/OASIS files.
	3D Export	• Generate Mesh	Export SEMulator3D models to other modeling platforms.
	3D Reader	• 3D Model Reader	Disseminate 3D model results across teams.

Summary

The SEMulator3D platform enables a new methodology for developing advanced semiconductor and MEMS processes. It is the fastest, most robust, and most accurate 3D semiconductor process modeling platform in the industry. SEMulator3D's process-predictive capabilities benefit all participants in the semiconductor supply chain, from technology developers to fabless IP providers to equipment and process vendors.