The MINIMOS Simulator and TUV Perspective on TCAD
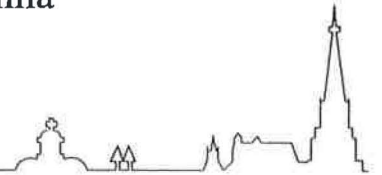
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Outline

- The Evolution of MINIMOS

- From Tools to Tasks

- TCAD Priorities

    Process Modeling

    Device/Interconnect Modeling

    Tool Integration

- Far Away in Time?

The Evolution of MINIMOS

First Version	**1980**
Impact Ionization	**1982**
Energy Balance	**1987**
Low Temperature	**1989**
Three-Dimensional Version	**1990**
Monte-Carlo	**1993**
MINIMOS-NT	**now**

MINIMOS—A Two-Dimensional MOS Transistor Analyzer

SIEGFRIED SELBERHERR, MEMBER, IEEE, ALFRED SCHÜTZ, AND HANS WOLFGANG PÖTZL, MEMBER, IEEE

Abstract—We describe a user-oriented software tool—MINIMOS—for the two-dimensional numerical simulation of planar MOS transistors. The fundamental semiconductor equations are solved with sophisticated programming techniques to allow very low computer costs. The program is able to calculate the doping profiles from the technological parameters specified by the user. A new mobility model has been implemented which takes into account the dependence on the impurity concentration, electric field, temperature, and especially the distance to the Si–SiO$_2$ interface. The power of the program is shown by calculating the two-dimensional internal behavior of three MOST's with 1-μm gate length differing in respect to the ion-implantation steps. In this way, the threshold voltage shift by a shallow implantation and the suppression of punchthrough by a deep implantation are demonstrated. By calculating the output characteristics without and with mobility reduction, the essential influence of this effect is shown. From the subthreshold characteristics, the suppression of short-channel effects by ion implantation becomes apparent. The MINIMOS program is available for everyone for just the handling costs.

First MINIMOS License

LICENSEE :

William G. Oldham
Univ of Ca
EEES DEPT
UNIV OF CAL
BERKELEY CA
94720

COMPUTER FOR OPERATION :

CDC 6400
Univ of Cal, Berkeley

LICENSOR :

INSTITUT FÜR
PHYSIKALISCHE ELEKTRONIK
DER TECHNISCHEN UNIVERSITÄT WIEN
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A-1040 WIEN - AUSTRIA

1980-03-04

(Date)   (Signature)

LICENSEE :

W Oldham
7/15/80

(Date)   (Signature)

Analysis of Breakdown Phenomena in MOSFET's

ALFRED SCHÜTZ, MEMBER, IEEE, SIEGFRIED SELBERHERR, MEMBER, IEEE, AND HANS W. PÖTZL, MEMBER, IEEE

Abstract—An accurate two-dimensional self-consistent numerical model for MOS transistors which is able to predict avalanche behavior is presented. This model aims at a more principal understanding of the physical processes which arise from the avalanche effect and which eventually lead to breakdown. The system of the fundamental semiconductor equations with several generation/recombination mechanisms is solved. To improve the description of the ionization process, correction terms are introduced which account for the fact that the gate induced field does not cause ionization.

Holes which are generated in the pinch-off region by impact ionization cause a bulk current; the voltage drop at the parasitic bulk resistance initiates an internal feedback mechanism. Thus a negative resistance branch of the drain current characteristic can arise. However, at high current levels, introduced by a high gate bias and/or a short channel, this snap-back effect is often counterbalanced by strong recombination. Snap-back voltage can be estimated with this model.

MINIMOS 3: A MOSFET Simulator that Includes Energy Balance

WILFRIED HÄNSCH AND SIEGFRIED SELBERHERR, SENIOR MEMBER, IEEE

Abstract—We present a model for hot carrier transport which is implemented in the device simulator MINIMOS 3. A brief resume of the model is given. We present various results which were calculated with this new model. We show that the *I–V* characteristics of a MOSFET can be calculated from $L_{eff} = 10$ µm down to $L_{eff} = 0.9$ µm with one parameter set. Modifications of carrier and current distributions are presented that show how hot carrier effects tend to smooth these distributions. Implications are discussed how a self-consistent carrier temperature can be used to model impact ionization and oxide injection.

MOS Device Modeling at 77 K

SIEGFRIED SELBERHERR, SENIOR MEMBER, IEEE

Abstract—The state of the art in self-consistent numerical low-temperature MOS modeling is reviewed. The physical assumptions that are required to describe carrier transport at low ambient temperatures are discussed. Particular emphasis is put on the models for space charge (impurity freeze-out), carrier mobility (temperature dependence of scattering mechanisms at a semiconductor–insulator interface), and carrier generation-recombination (impact ionization). The differences with regard to the numerical methods required for the solution of low-temperature models compared to room-temperature models are explained. Typical results obtained with the simulator MINIMOS 4 are presented. These include comparisons of short-channel effects and hot-electron phenomena such as energy relaxation and avalanche breakdown at 77 and 300 K ambient temperature.

Numerical Treatment of Nonrectangular Field-Oxide for 3-D MOSFET Simulation

MARTIN THURNER, MEMBER, IEEE, PHILIPP LINDORFER, AND SIEGFRIED SELBERHERR, SENIOR MEMBER, IEEE

Abstract—Presently there exists only a few three-dimensional simulation programs that take into account effects at the channel edge due to nonplanar interfaces. The finite element method is mostly used for discretization to deal with those interfaces. Another approach has been successfully implemented into MINIMOS to simulate three-dimensional effects. We applied the box integration method after Forsythe for discretization. This method is excellently suitable for nonplanar interfaces. The most important nonplanar interface occurs at the transition of the gate oxide to the field oxide, which is commonly called "bird's beak." Approximating this interface with right angles leads to unrealistic results. This paper introduces the new numerical treatment in three-dimensional MOSFET simulation with nonplanar interfaces. We present the physical model used and show the numerical implementation of the basic equations. The simulations have been carried out with MINIMOS 5, our fully three-dimensional simulation program. Three-dimensional effects like threshold shift for small channel devices, channel narrowing, and the enhanced conductivity at the channel edge have been successfully modeled.

A Hybrid Device Simulator that Combines Monte Carlo and Drift-Diffusion Analysis

Hans Kosina, *Member, IEEE*, and Siegfried Selberherr, *Fellow, IEEE*

Abstract—A hybrid simulator suitable for modeling small semiconductor devices has been developed in which Monte Carlo and drift-diffusion models are combined. In critical device regions, the position-dependent coefficients of an extended drift-diffusion equation are extracted from a Monte Carlo simulation. Criteria for identifying these regions are described. Additional features which make the code more efficient are presented. First, a free-flight time calculation method using a new self-scattering algorithm is described. It allows for an efficient reduction of self-scattering events. Second, a unique Monte Carlo-Poisson coupling scheme has been developed which converges faster than all presently known schemes. It exploits the so-called Monte Carlo-drift diffusion coupling technique, which also forms the basis of the hybrid method. The simulator has been used to model submicron MOSFET's with gate lengths down to 0.15 μm. In addition to the non-local effects occurring in these devices, the performance of the hybrid simulation method is analyzed.

Simulation of Submicron Double-Heterojunction High Electron Mobility Transistors with MINIMOS-NT

Thomas Simlinger[†], Helmut Brech[‡], Thomas Grave[‡], and Siegfried Selberherr[†]

Abstract—Simulations and measurements of submicron pseudomorphic high electron mobility transistors (HEMTs) are presented. For the simulations the generic device simulator MINIMOS-NT is used which is capable of dealing with complex device geometries as well as with several physical models represented by certain sets of partial differential equations. A description of the structure of the simulator is given, which shows the basic idea of splitting the device geometry into distinct regions. Within these "segments", arbitrary material properties and physical models, i.e., partial differential equations, can be defined independently. The segments are linked together by interface models which account for the interface conditions. The simulated characteristics of a HEMT with a gate length of 240 nm are compared with the measured data. Essential physical effects which determine the behavior of the device can be identified in the output and transfer characteristics.
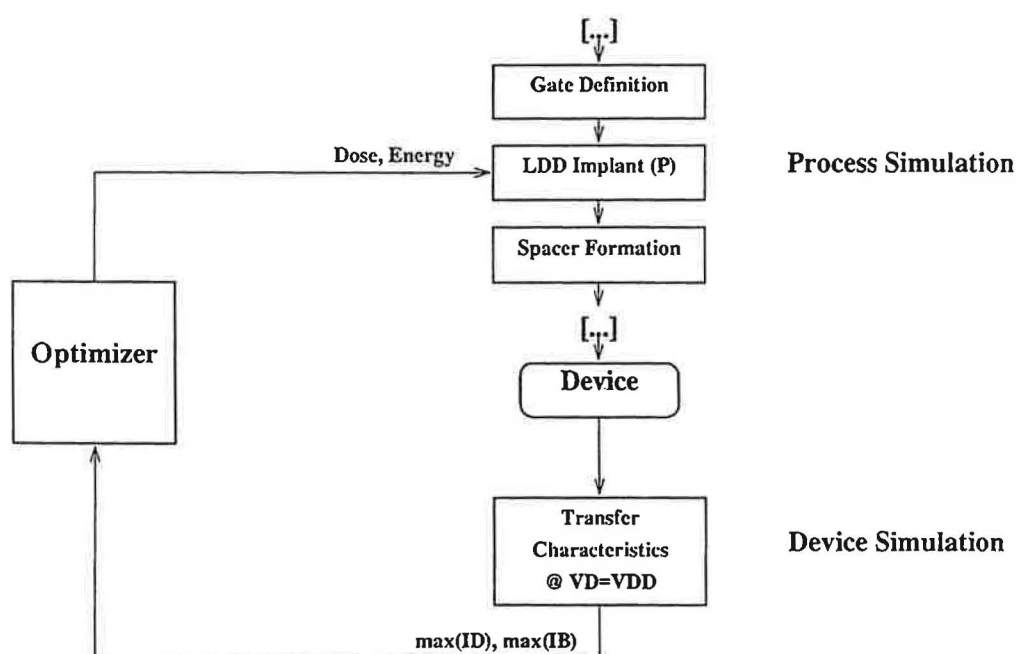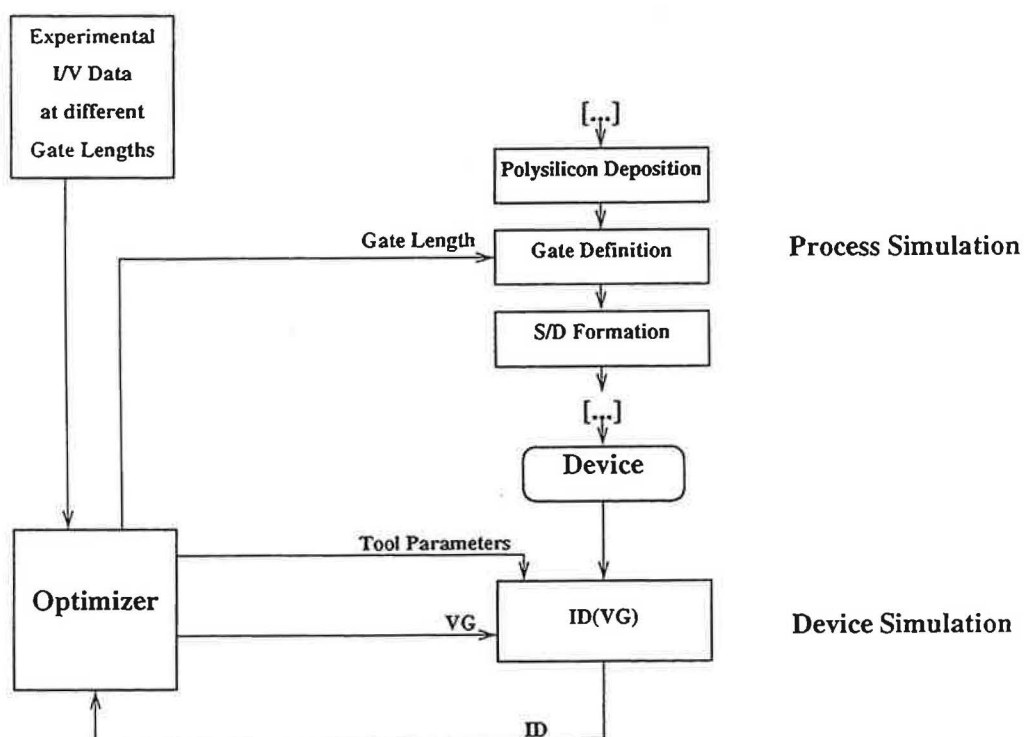
From Tools to Tasks

Examples:

• LDD Implant Optimization

• Tool Calibration

• Process Design Centering
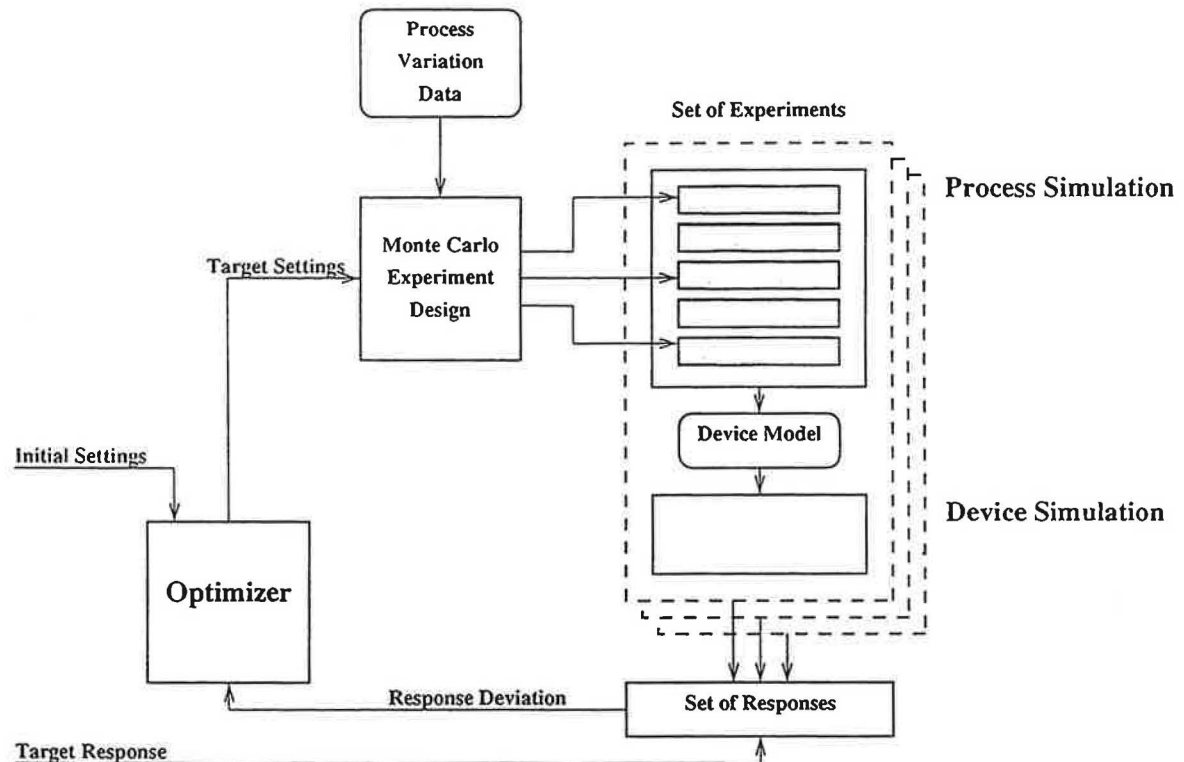
• Generic Optimization

• ...

⇨ Technology CAD
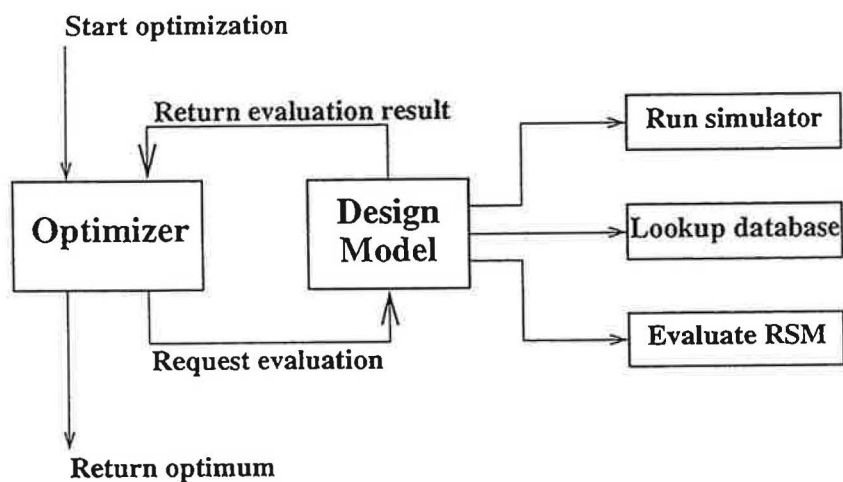
LDD Implant Optimization

[.ͳ.]

Gate Definition

Dose, Energy → LDD Implant (P)   **Process Simulation**

Spacer Formation

[.ͳ.]

Device

Optimizer

Transfer
Characteristics
@ VD=VDD   **Device Simulation**

max(ID), max(IB)

Tool Calibration

Experimental
I/V Data
at different
Gate Lengths

[.ͳ.]

Polysilicon Deposition

Gate Length → Gate Definition   **Process Simulation**

S/D Formation

[.ͳ.]

Device

Optimizer

Tool Parameters

VG → ID(VG)   **Device Simulation**

ID

Process Design Centering

Generic Optimization

Technology CAD

TCAD Priorities

Process Modeling

- Defect Controlled Diffusion

   Damage Behavior

   Transient Diffusion

   Contamination Transfer

- Etch Parameters

- Silcide Formation

- Optical Proximity Correction

TCAD Priorities

Device/Interconnect Modeling

- Parameter Extraction

- Interconnect Delay

- Advanced Carrier Transport

- Compact Models (L<0.3μm)

- Reliability

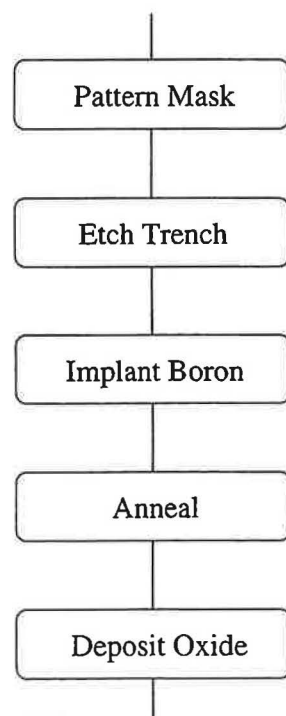# TCAD Priorities

Tool Integration

- Automatic Meshing

- Tool Coupling

- Optimization

- Inverse Modeling

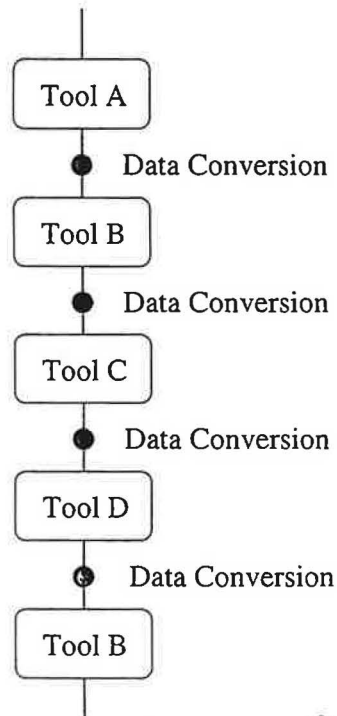- Human/Machine Interface

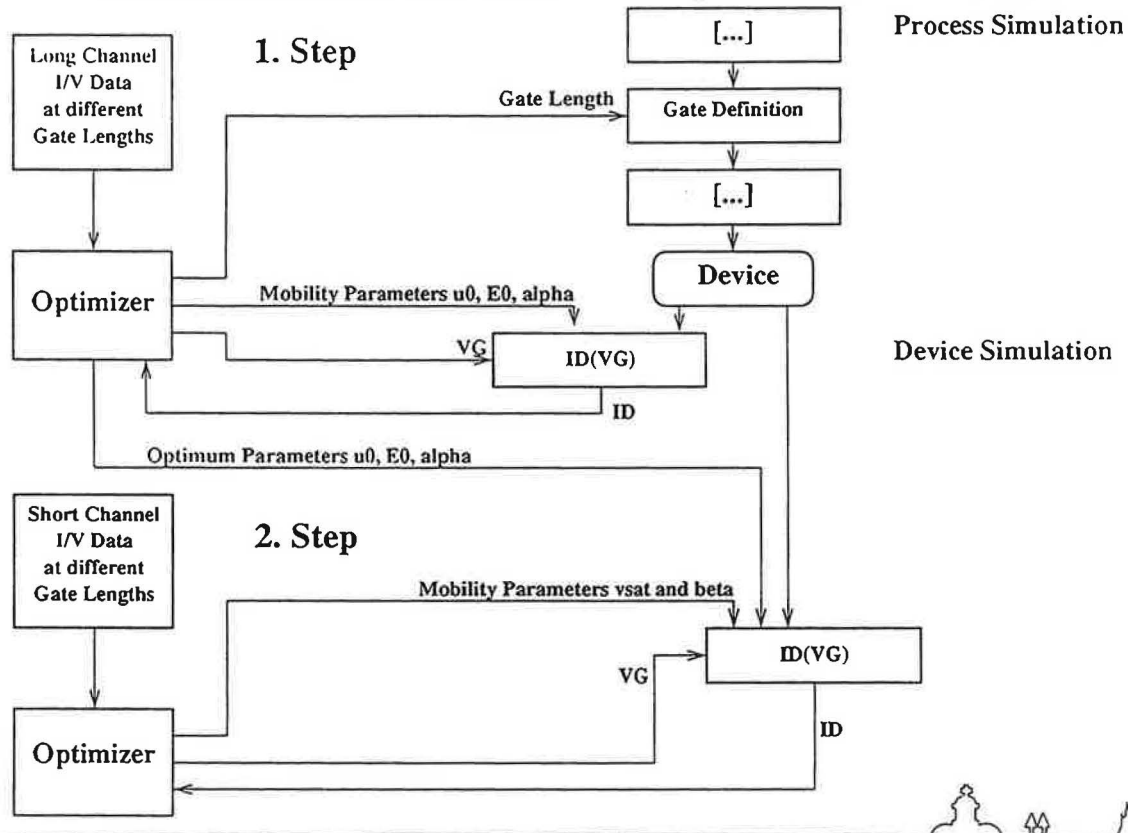# Tesselation for a Tetrahedron
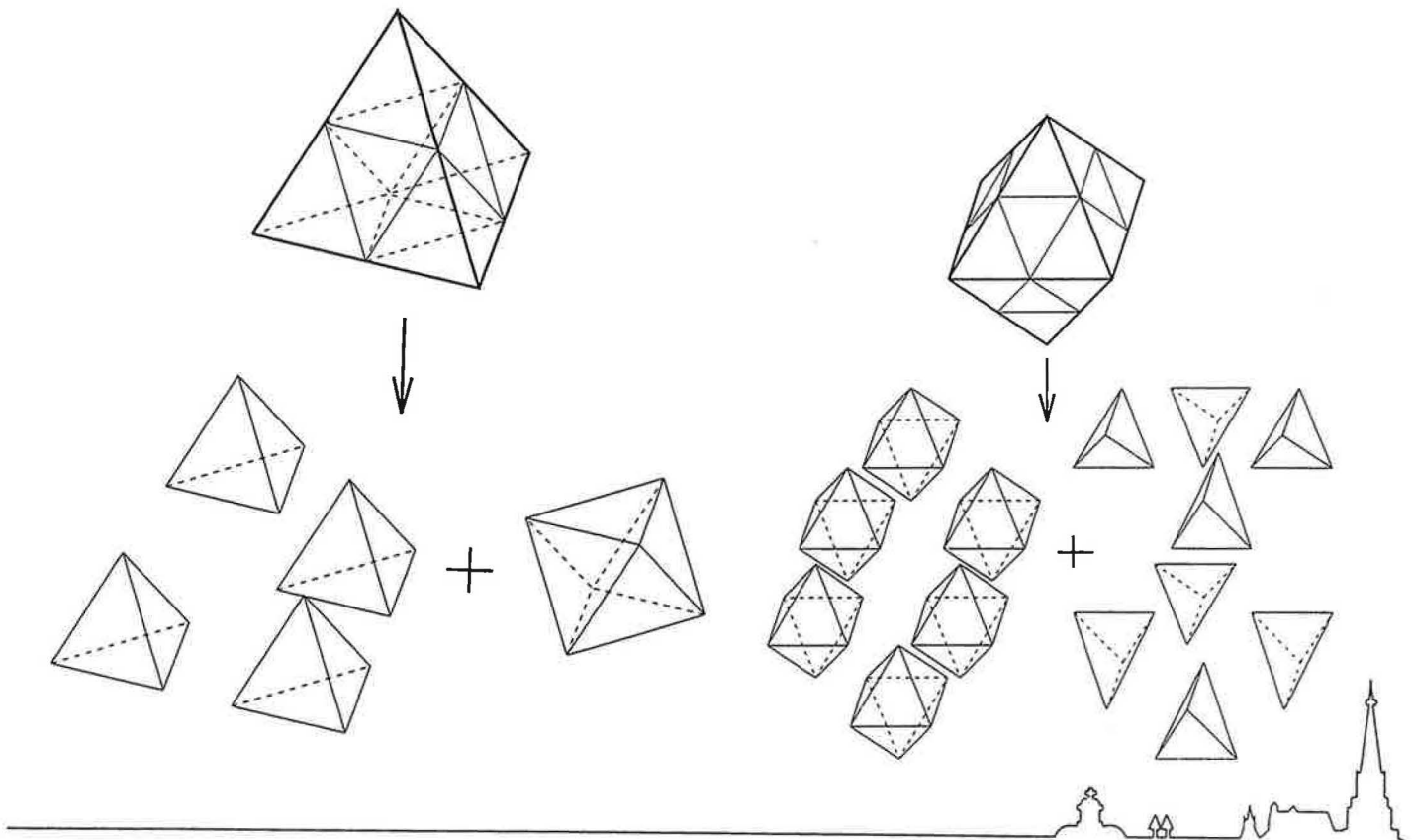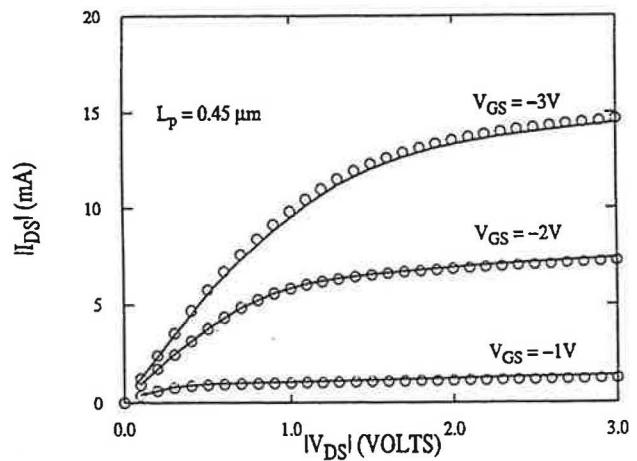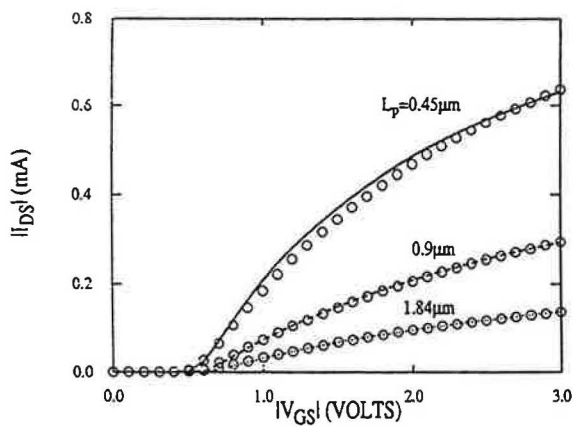

A Typical TCAD Application

Process Flow	Simulation Flow	
Pattern Mask	Tool A	
	●	Data Conversion
Etch Trench	Tool B	
	●	Data Conversion
Implant Boron	Tool C	
	●	Data Conversion
Anneal	Tool D	
	●	Data Conversion
Deposit Oxide	Tool B	

Calibration of Mobility Parameters

1. Step

Long Channel I/V Data at different Gate Lengths → Optimizer

Process Simulation

[...] → Gate Length → Gate Definition → [...] → Device

Optimizer — Mobility Parameters u0, E0, alpha → ID(VG)

Device Simulation

VG → ID(VG) → ID

2. Step

Optimum Parameters u0, E0, alpha

Short Channel I/V Data at different Gate Lengths → Optimizer

Mobility Parameters vsat and beta → ID(VG)

VG → ID(VG) → ID

Calibration of Mobility Parameters

Left plot: $|I_{DS}|$ (mA) vs $|V_{GS}|$ (VOLTS), with curves labeled $L_p=0.45\mu m$, $0.9\mu m$, $1.84\mu m$.

Right plot: $|I_{DS}|$ (mA) vs $|V_{DS}|$ (VOLTS), $L_p = 0.45\,\mu m$, with curves labeled $V_{GS} = -3V$, $V_{GS} = -2V$, $V_{GS} = -1V$.
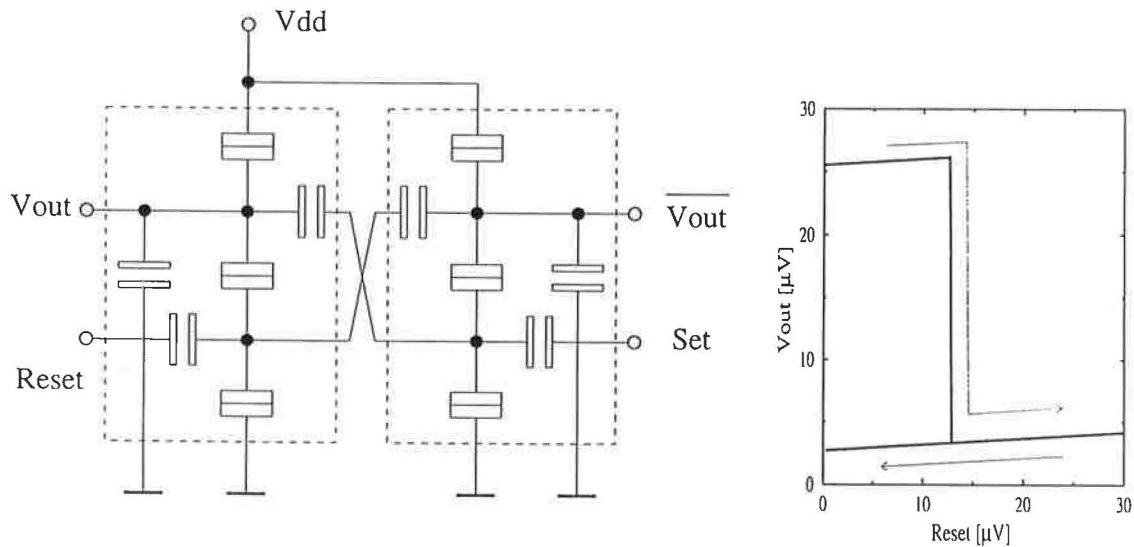
Far Away in Time?

- Equipment-Integrated Process Models

- Structured Process Synthesis
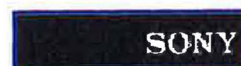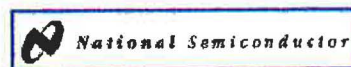
- Single Electron Electronics

Time Passes by Quickly!

SIMON

A Multi-Purpose Single Electron Device and Circuit Simulator

First Version Available

Our Industrial Partners