Use of simulation software in microelectronics

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Simulation software

- **Simulation programs:**
  - + Solve numerically physical equations
  - + Emulate logical operation
- **Under specific assumptions and simplifications**
  - + Physical laws
  - + Algorithms
  - + Initial states
- **Only in limited finite number of points**
  - + In spatial coordinates
  - + In temporal evolution
  - + In logical states
- **There are errors**

Simulation software

- To reduce errors we can refine equations and grid
  - + More accurate equations
  - + More second order effects
  - + Finer spatial grid
  - + Finer temporal resolutions

- Computing time increases

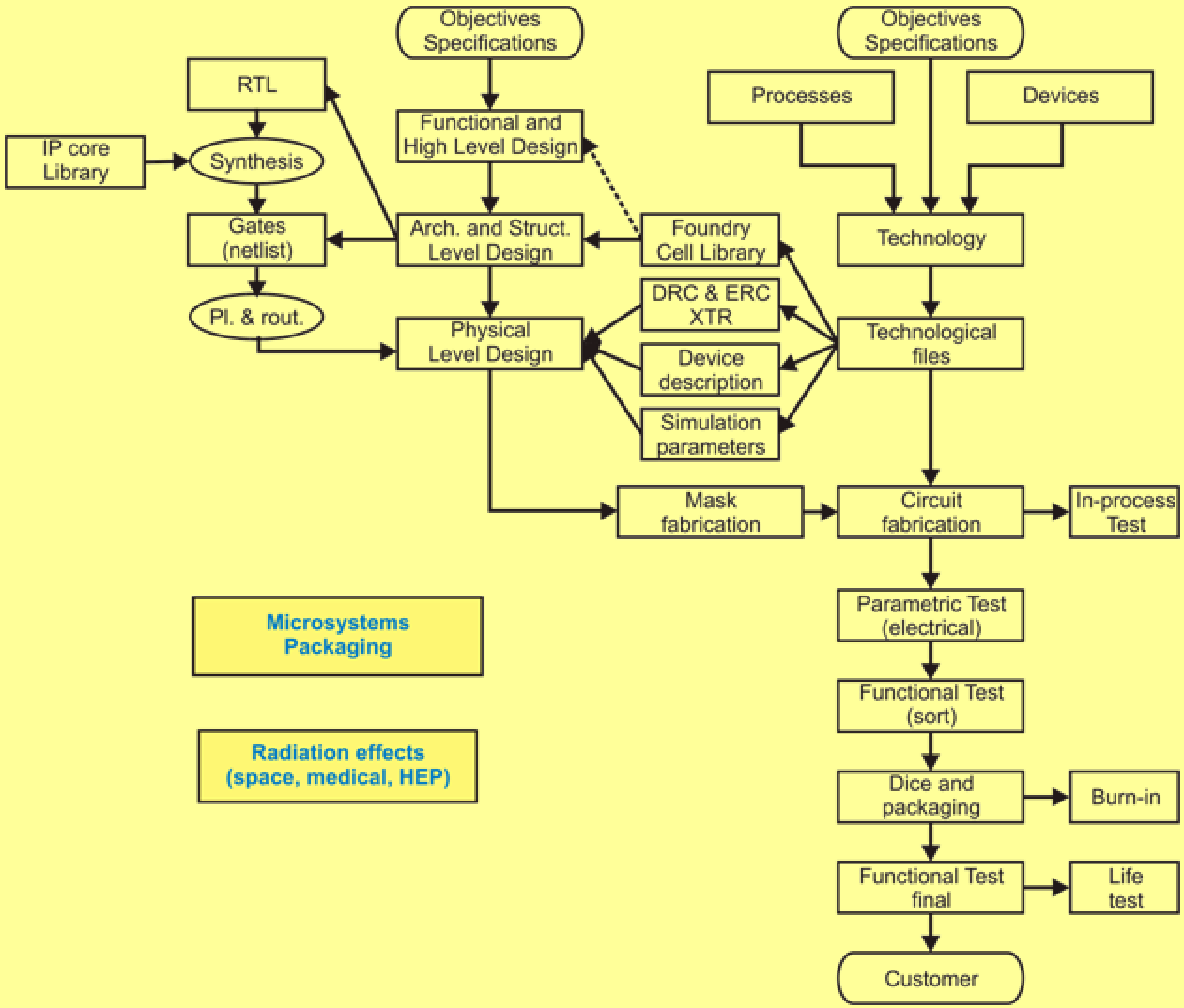
- In order to reduce computing time we make simplifications
  - + Models

What to simulate

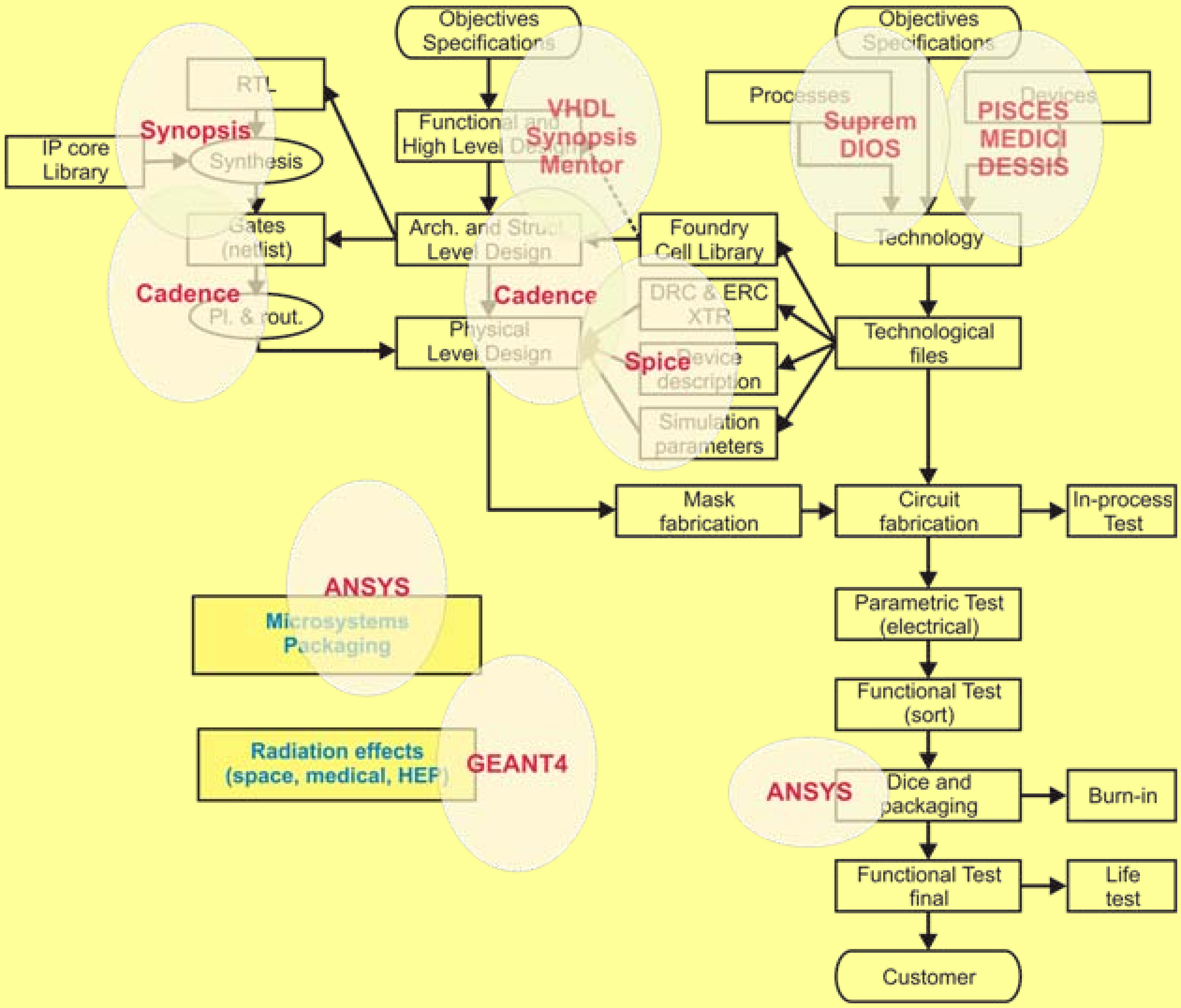
- **Behavioral models ➔ Simulink, ADS**
- **Functional and System ➔ Level System Verilog, System C**
- **Logical and RTL ➔ VHDL, Verilog**
- **Electrical Circuits ➔ SPICE, Spectre**
- **Microelectronic Processes ➔ Suprem, Dios**
- **Electronic devices ➔ Pisces, Medici, Atlas, Minimos**
- **Mechanical devices ➔ Ansys, Coventor**
- **Radiation behavior ➔ Geant4**

- **Computer sophistication:**
  - **1D, 2D, 3D**
  - **Static, transient**

ASIC development flow



ASIC development flow



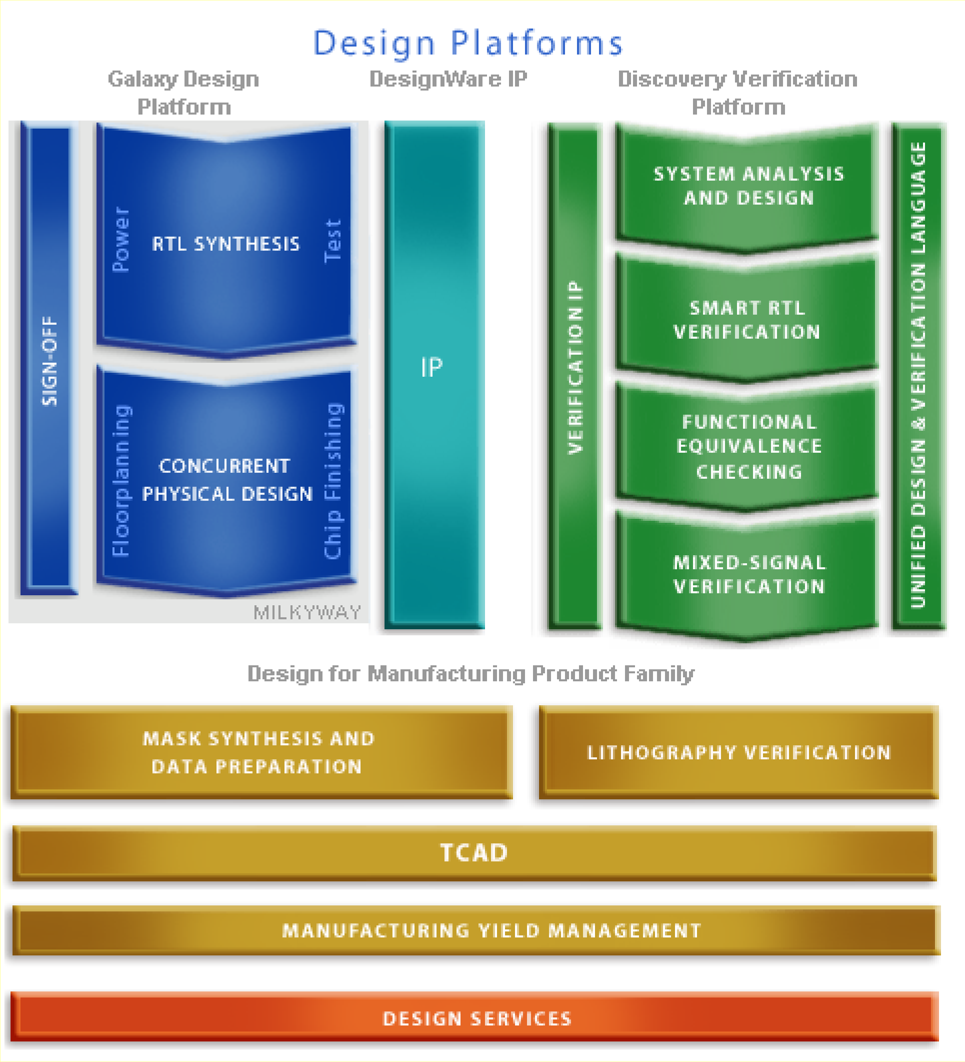
Available software

- TMA (TSUPREM4, MEDICI)
- ISE-TCAD
- SILVACO (ATHENA, ATLAS)

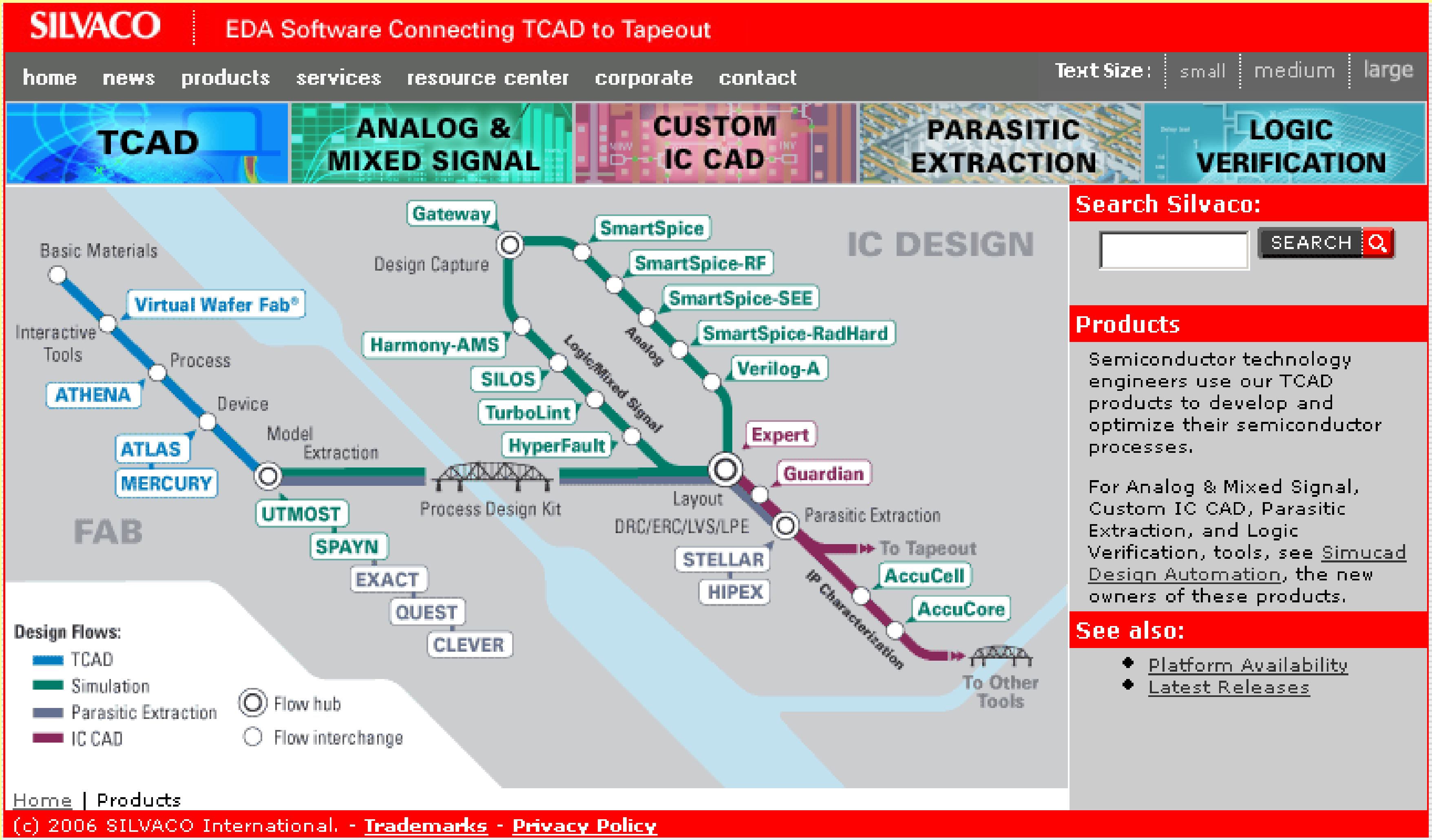
Available software

- TMA (TSUPREM4, MEDICI)
- ISE-TCAD
- **SENTAURUS**
- SILVACO (ATHENA, ATLAS)

Synopsis packages



Silvaco packages



SPICE
Electrical Circuit
Full Custom Analog Design

SPICE

- SPICE: developed at University of California-Berkeley. Most widely used computer program package for EEs.
- General purpose analog simulator, containing models for most circuit elements.
- Outstanding tool for precise simulations of complex, non-linear circuits.
- Main analyses:
  - DC
  - Transient
  - AC
- However: Only as good as the device models and parameter values used "Garbage in, garbage out"

SPICE

- **Purpose: Perform numerical circuit analysis**
- **Method:**
  - + **Represent each circuit element by a mathematical model**
  - + **Enforce Kirchoff's laws at all nodes**
  - + **Solve resulting set of equations of the type:**

$$F(x, \dot{x}, t) = 0$$

F: linear/nonlinear operator

x: unknown vector of circuit variables (current, voltage)

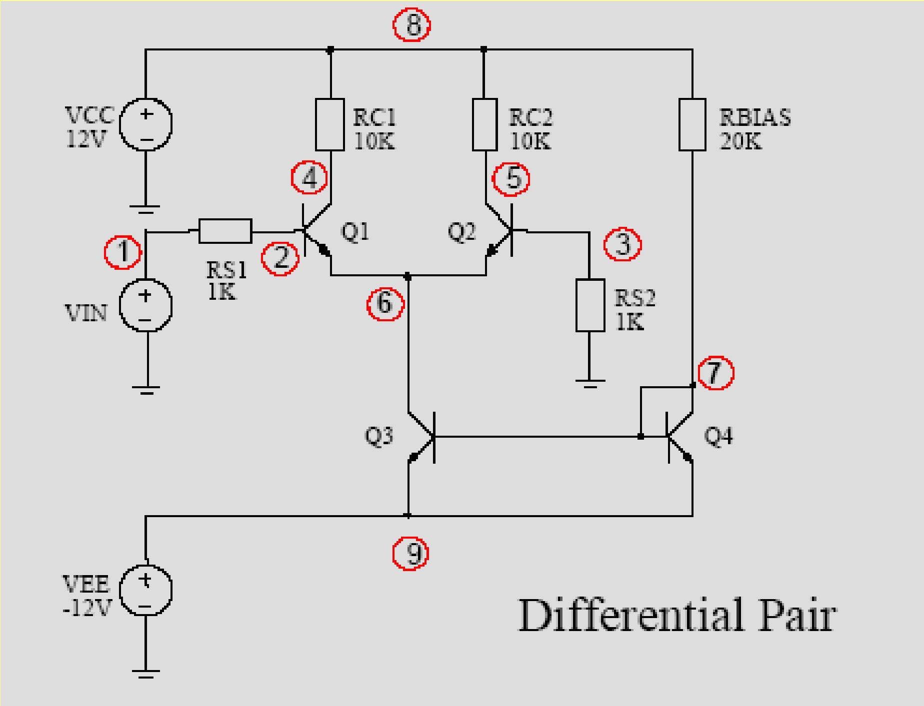
- **DC analysis: Stationary equations– iteration/matrix method**
- **AC analysis: Linearize around the operating point**
- **Transient analysis: DC analyses and numerical integration**

SPICE

- **Infinite varieties:**
  + **SPICE2/3**
  + **HSPICE**
  + **Spectre**
  + **Pspice**

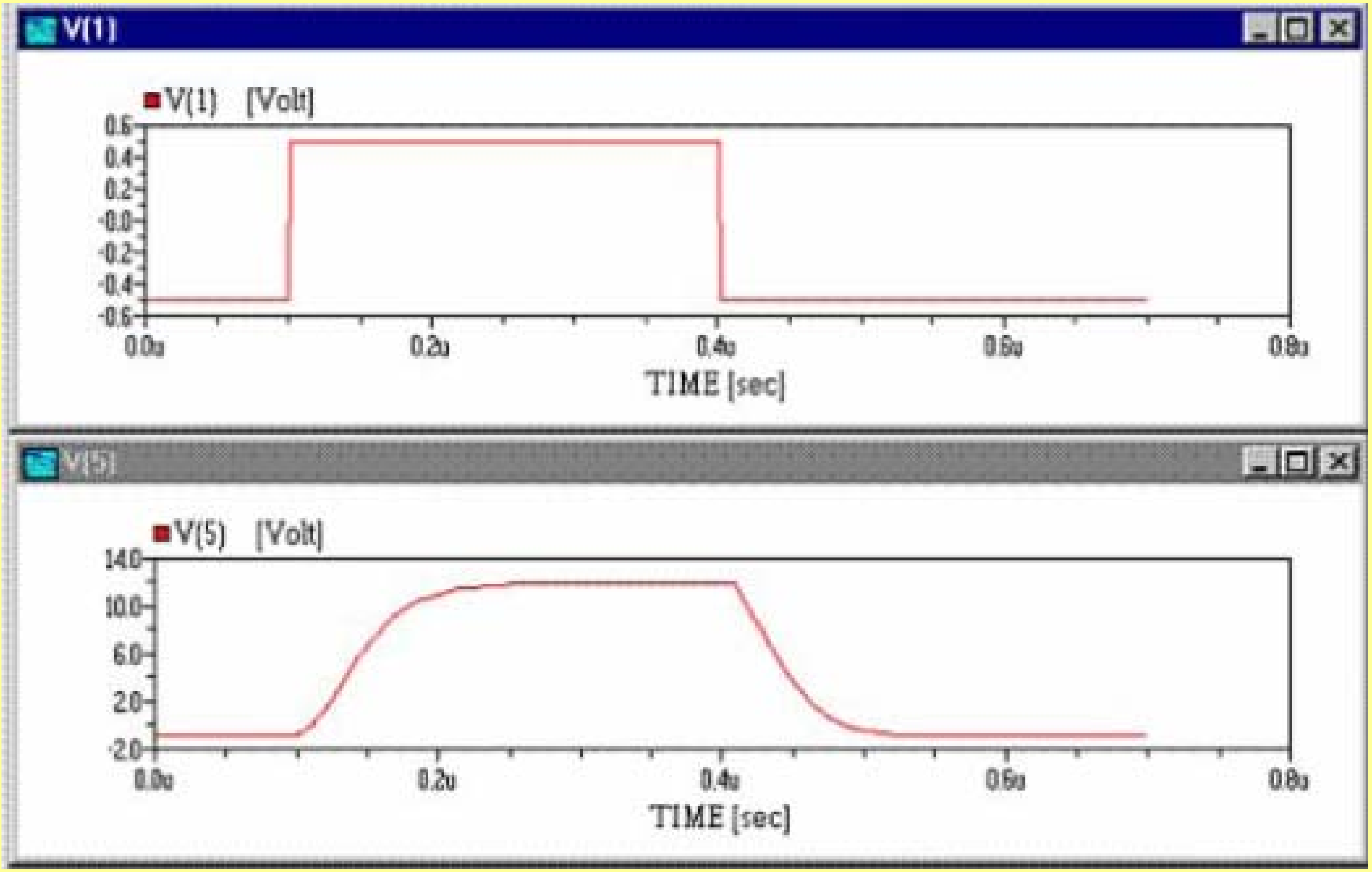
- **Many models (>80)**
  + **MOSFET: (Level 1, 2, 3), BSIM3V3, BSIM4, EKV, Philips**
  + **BJT: VBIC, Mextram, UCSD-HBT, HICUM**
  + **JFET/MESFET**
  + **TFT**
  + **Diode**
  + **Resistors, capacitors, transmission lines, ...**

SPICE Example




```
VIN 1 0 DC 0 + PULSE(-0.5
+ 0.5 0.1u 1n 1n 0.3u 2u) AC 1
VCC 8 0 12
VEE 9 0 -12
Q1 4 2 6 QNL
Q2 5 3 6 QNL
RS1 1 2 1K
RS2 3 0 1K
RC1 4 8 10K
RC2 5 8 10K
Q3 6 7 9 QNL
Q4 7 7 9 QNL
RBIAS 7 8 20K
.MODEL QNL NPN(BF=80 RB=100
+ CJS=2PF TF=0.3NS TR=6NS
+ CJE=3PF CJC=2PF VA=50)
```

SPICE Example



SPICE Models

- **Diode Model Parameters**

SPICE parameter	SPICE parameter name	Units	SPICE default	Chapter 1 notation
IS	Saturation current	A	1.0e-14	I_S
RS	Series resistance	Ω	0	R_S
N	Ideality factor	-	1	η
TT	Transit time	s	0	-
CJO	Zero bias capacitance	F	0	-
VJ	Built-in voltage potential	V	1	-
M	Grading coefficient	-	0.5	-
EG	Energy gap	eV	1.11	-
XTI	Saturation current temperature exponent	-	3.0	-
KF	Flicker noise coefficient	-	0	-
AF	Flicker noise exponent	-	1	-
FC	Coefficient for forward-bias depletion capacitance	-	0.5	-
BV	Reverse breakdown voltage	V	infinite	-
IBV	Current at breakdown	A	10^{-3}	-
TNOM	Temperature at which parameters are specified	°C	27	T (K) (T=TNOM+273)

HSPICE

- **Synopsis HSPICE specific features**
  - + **Behavioral Modeling with Verilog-A**
  - + **IC Cell Characterization**
  - + **RF Analysis**
  - + **Encrypted models**
  - + **Optimization techniques**
    - – **Corner analysis**
    - – **Monte Carlo**

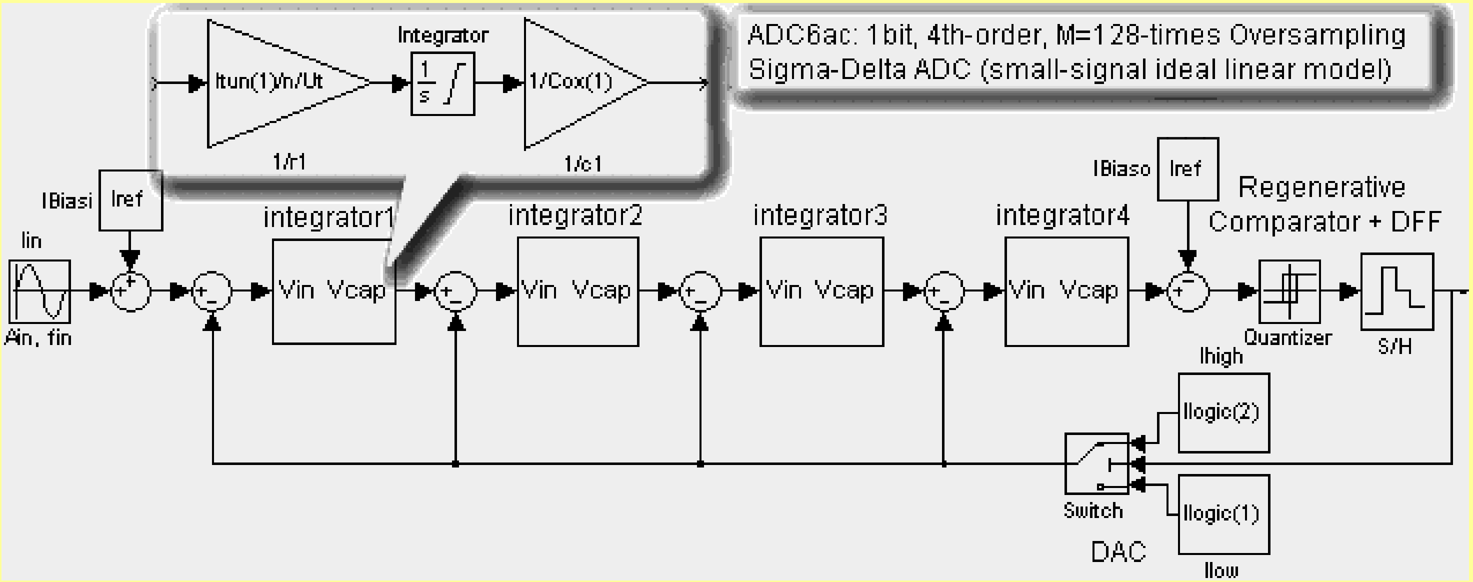
Full simulation

- Sigma-delta modulators are hard to simulate
- Problem in two time scales
  + Modulation frequency 1 kHz
  + Internal clock 1 MHz
- Full simulation > 64 clock periods = 75ms with 1μs resolution
- Total simulation time with Spectre (spice) = 1 month
- Not practical for design optimization

Need for combination of simulators

Solution

- **Use of MATLAB Simulink Macro Model**



- **Simulation time 50 sec**
- **Power scan = 50 points at different input power**
  + **Spice: 50 month**
  + **Simulink: 40 minutes**

Process Simulation

Process Simulation

- Allow the simulation of different fabrication processes, as well as complete technologies

- Started with unidimensional Suprem from Stanford University
  + Implant profiles
  + Thermal diffusion and oxidation
  + Layer deposition
  + Etching

- Still there are simple unidimensional programs (Silvaco SSUPREM3, ICECREM)

Process Simulation

- Simulators evolve to 2D with very accurate models
- Initially it was different programs for different topics:
  - Implant and thermal process
  - Deposition
  - Photolithography
  - Optics
- 2D and 3D separate programs
- Today all process are integrated in the same program, except specialized features
  - Deep submicron lithography
  - Parasitic extraction
- Today 1D, 2D and 3D are integrated in the same program

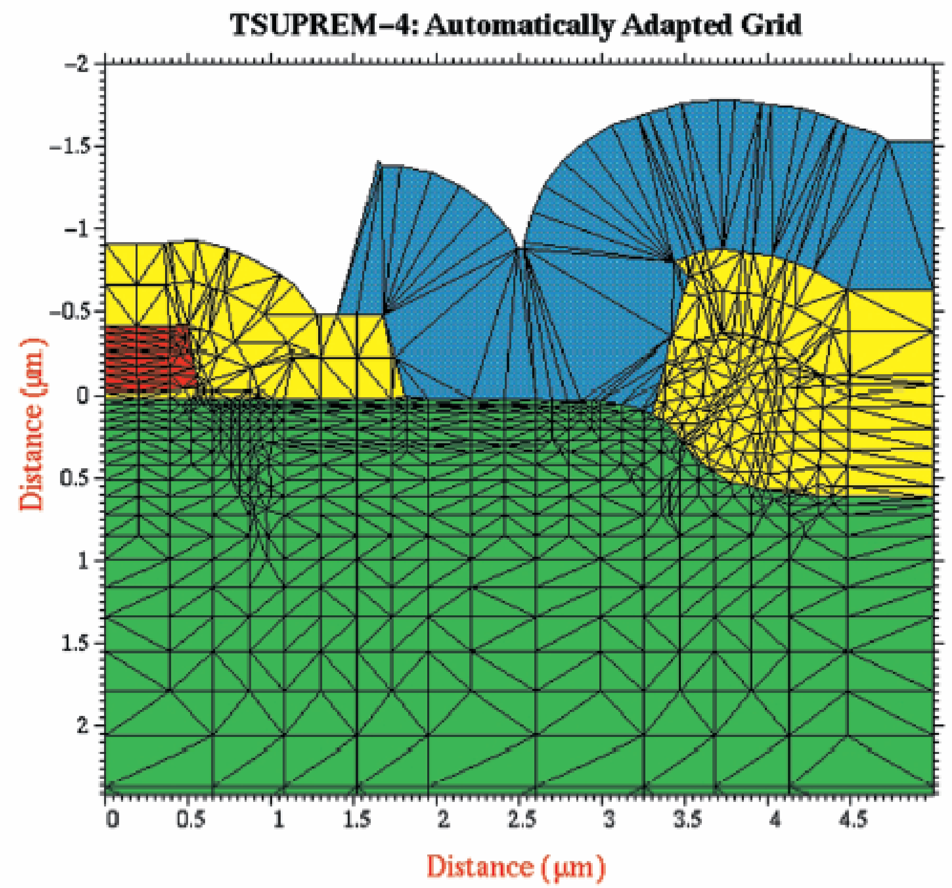
Process Simulation Benefits

- Design state of the art devices, from big power transistors to sub-micron devices
- Predict 1, 2 and 3 dimensional device structure characteristics
- Evaluate and refine conventional and novel isolation technologies, such as LOCOS, SWAMI, deep trench and shallow trench isolation
- Analyze stress history in all layers as a result of thermal oxidation, silicidation, thermal mismatch, etching, deposition, and stress relaxation at high temperatures
- Determine basic electrical device characteristics, such as sheet resistance, threshold voltage and C-V curve (including quantum-mechanical correction)
- Link process structures for two-and three-dimensional device analysis using Avant!'s with device simulators

MESH

- The key for an accurate simulation is to use a good mesh of the area of interest
- There are automatic mesh generation
- Tools for local mesh refinement
- Structure and mesh editors

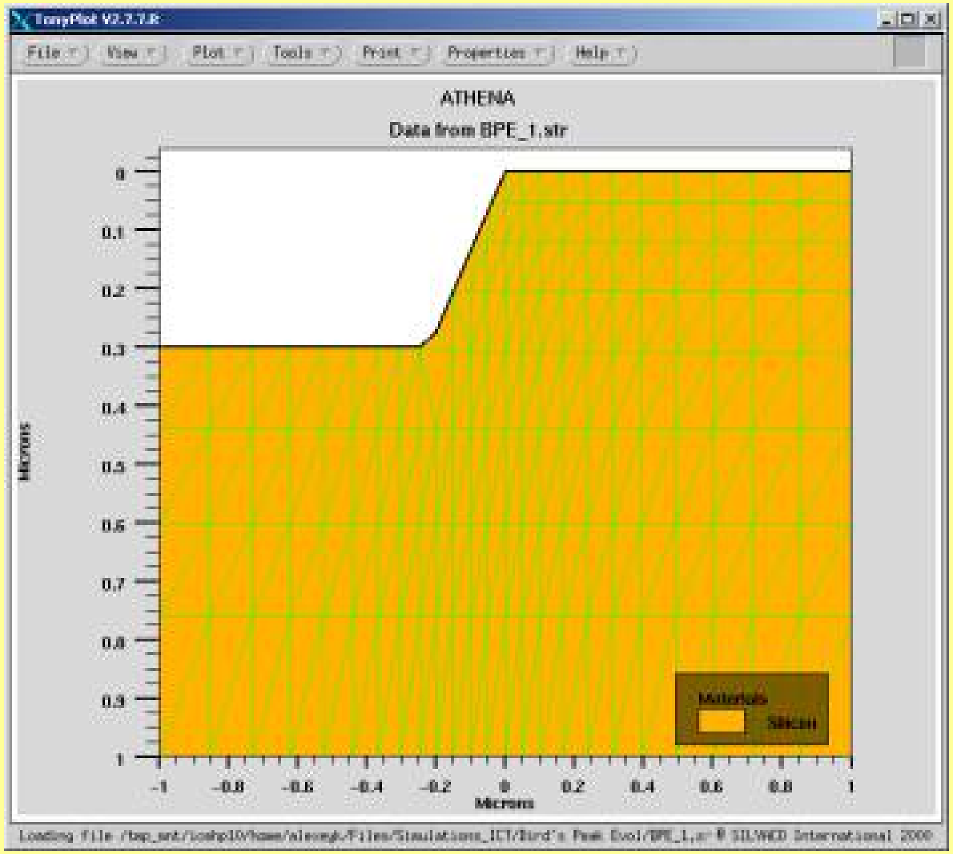
- It is important to keep mesh nodes at a minimum to avoid extreme (months) processing times



Automatically generated mesh.

Mesh generation example

```
go athena
#TITLE: Oxide Profile Evolution Example
# Substrate mesh definition
line y loc=0    spac=0.05
line y loc=0.6  spac=0.2
line y loc=1
line x loc=-1   spac=0.2
line x loc=-0.2 spac=0.05
line x loc=0    spac=0.05
line x loc=1    spac=0.2
init orient=100
```

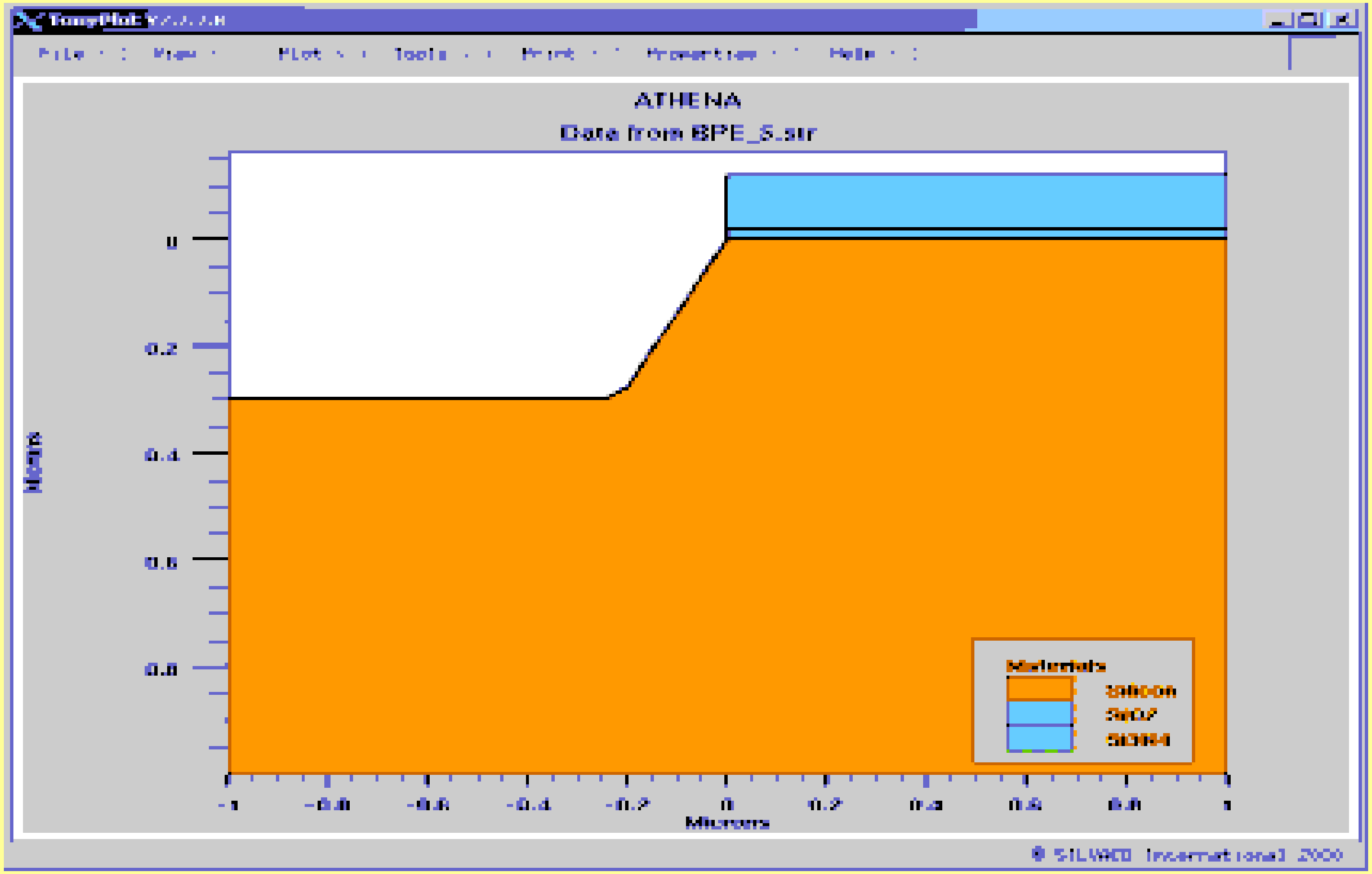


Process Models

- Accurate models are also crucial.
- Models depend on equipment manufacturer
- Software vendors distribute library models for most equipments in the market
- Many second order effects incorporated in last soft versions

- Nevertheless, process simulation is not a straightforward task, and requires deep technology knowledge.
  - + There are hundreds of models to choose
  - + There are thousands of parameters to choose

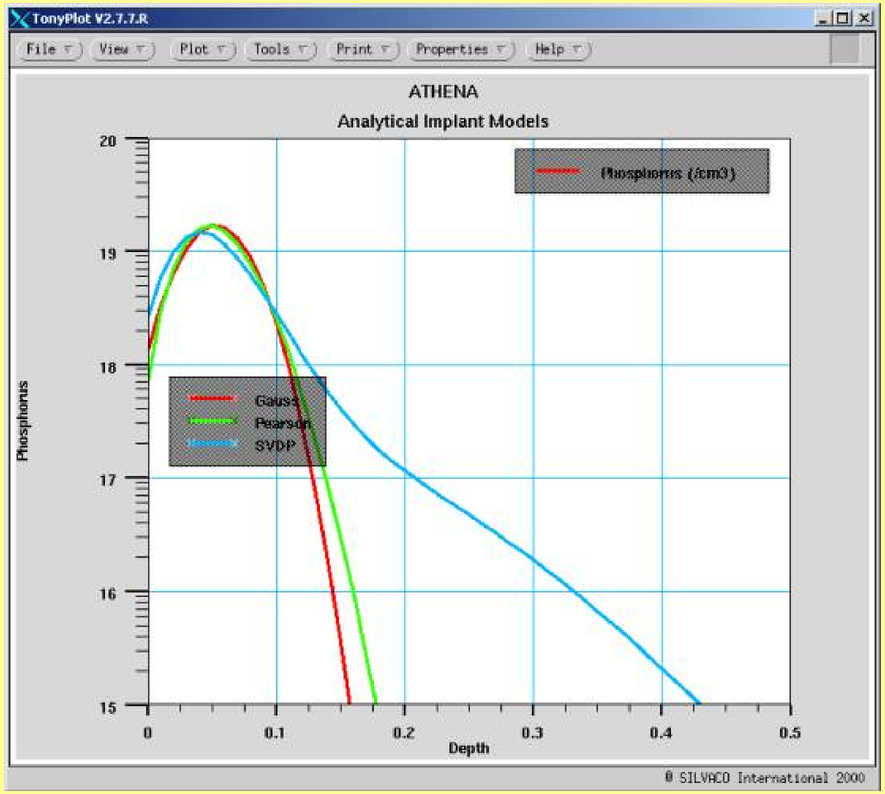
Example: Bird beak's LOCOS evolution



Example: Implant models

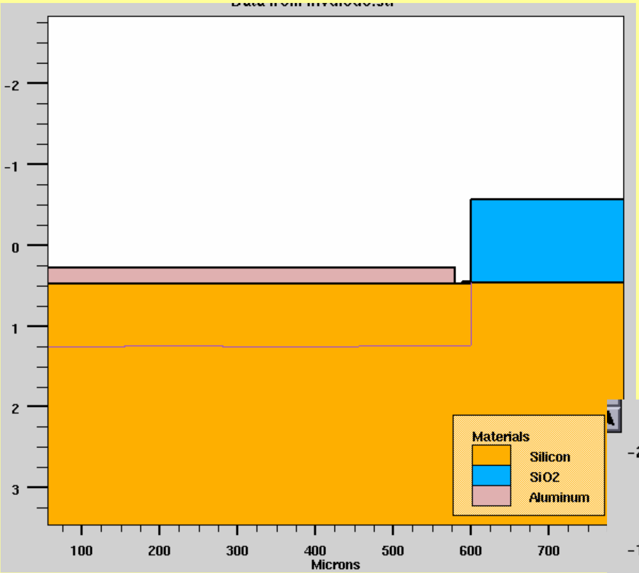
Comparison of Gauss, Pearson and SVDP methods

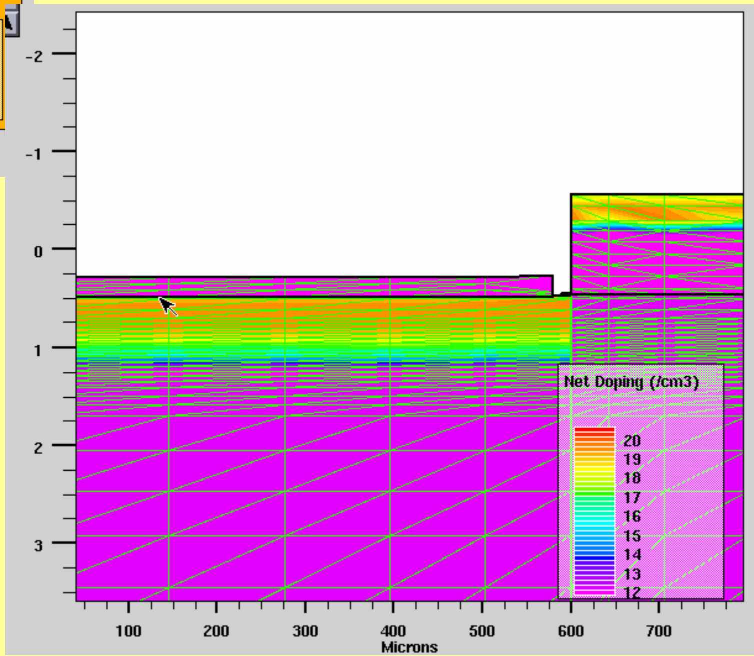
```
# Gauss (symmetrical) implant
# (parameters are in std_tables)
moments std_tables
implant phos dose=1e14 energy=40
   gauss


implant phos dose=1e14 energy=40
   pearson print.mom


#Use SVDP method (default)
moments svdp_tables
implant phos dose=1e14 energy=40
   print.mom
```



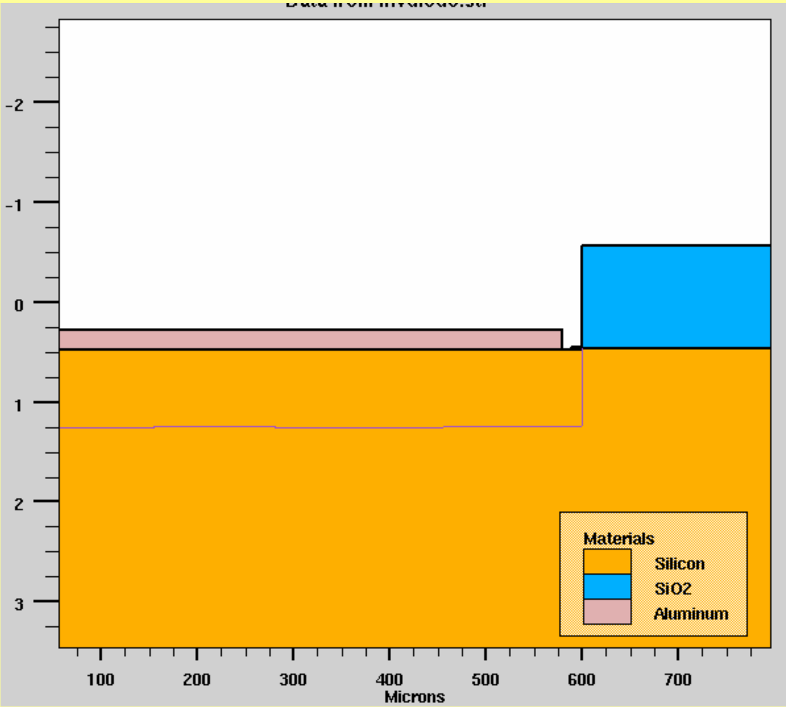
Technology Simulation: Diode

- go athena
-
- line x loc=0.00 spac=150
- line x loc=599.7 spac=150
- line x loc=600.3 spac=0.1
- line x loc=600.6 spac=0.05
- line x loc=600.9 spac=0.1
- line x loc=601.0 spac=50
- line x loc=800.0 spac=150
- #
- line y loc=0.0 spac=0.5
- line y loc=0.5 spac=0.5
- line y loc=0.7 spac=0.1
- line y loc=0.8 spac=0.05
- line y loc=1.3 spac=0.05
- line y loc=1.5 spac=0.1
- line y loc=1.7 spac=0.5
- line y loc=280   spac=50





Technology Simulation: Diode

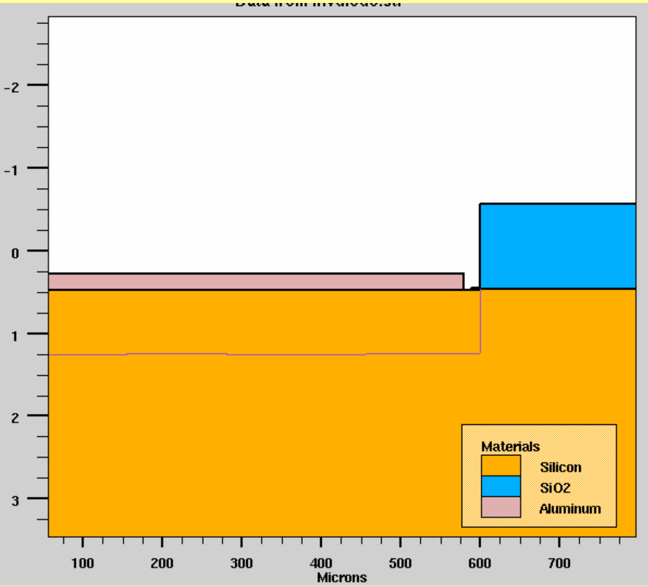


•init silicon c.phosphor=1e12 orientation=100 two.d

•# Field Oxidation
•#include ohc-10000.ss3
•diffus temp=800 time=10 f.n2=6.0
•diffus temp=800 time=60 f.n2=6.0 t.final=1100
•diffus temp=1100 time=2 f.n2=6.0
•diffus temp=1100 time=1 f.o2=6.0
•diffus temp=1100 time=10 f.o2=6.0
•diffus temp=1100 time=145 f.h2=5.0 f.o2=3.5
•diffus temp=1100 time=10 f.o2=6.0
•diffus temp=1100 time=65 f.n2=6.0 f.o2=1.0 t.final=800
•diffus temp=800 time=2 f.n2=6.0 f.o2=1.0
•diffus temp=800 time=10 f.n2=6.0
•#
•extract name="field oxide" thickness material="SiO2" mat.occno=1 / x.val=100 datafile="invdiodo.final“

•field oxide=10271.4 angstroms (1.02714 um) X.val=100

Technology Simulation: Diode



- etch oxide left p1.x=600

- # Gate Oxidation (36.5 nm)
- #include oxptaaa.ss3
- #
- diffus temp=800 time=10 f.o2=6.0
- diffus temp=800 time=30 f.o2=6.0 t.final=950
- diffus temp=950 time=2   f.o2=6.0
- diffus temp=950 time=45 f.o2=6.0 f.hcl=.12
- diffus temp=950 time=5   f.o2=6.0
- diffus temp=950 time=30 f.n2=6.0
- diffus temp=950 time=35 f.n2=6.0 t.final=800
- diffus temp=800 time=12 f.n2=6.0
- #
- extract name="gate oxide" thickness min.v=10 max.v=1000 material="SiO~2" \
-         mat.occno=1 x.val=100 datafile="invdiodo.final"

- gate oxide=384.608 angstroms (0.0384608 um) X.val=100

Technology Simulation: Diode

- #Implantacion Bor
- implant boron dose=1e15 energy=50 pearson tilt=7

- # Drive-in inert ambient
- diffus temp=800 time=10 f.n2=6.0
- diffus temp=800 time=10 f.n2=6.0
- diffus temp=800 time=30 f.n2=6.0 t.final=950
- diffus temp=950 time=2 f.n2=6.0
- diffus temp=950 time=30 f.n2=6.0
- diffus temp=950 time=35 f.n2=6.0 t.final=800
- diffus temp=800 time=2 f.n2=6.0
- diffus temp=800 time=10 f.n2=6.0

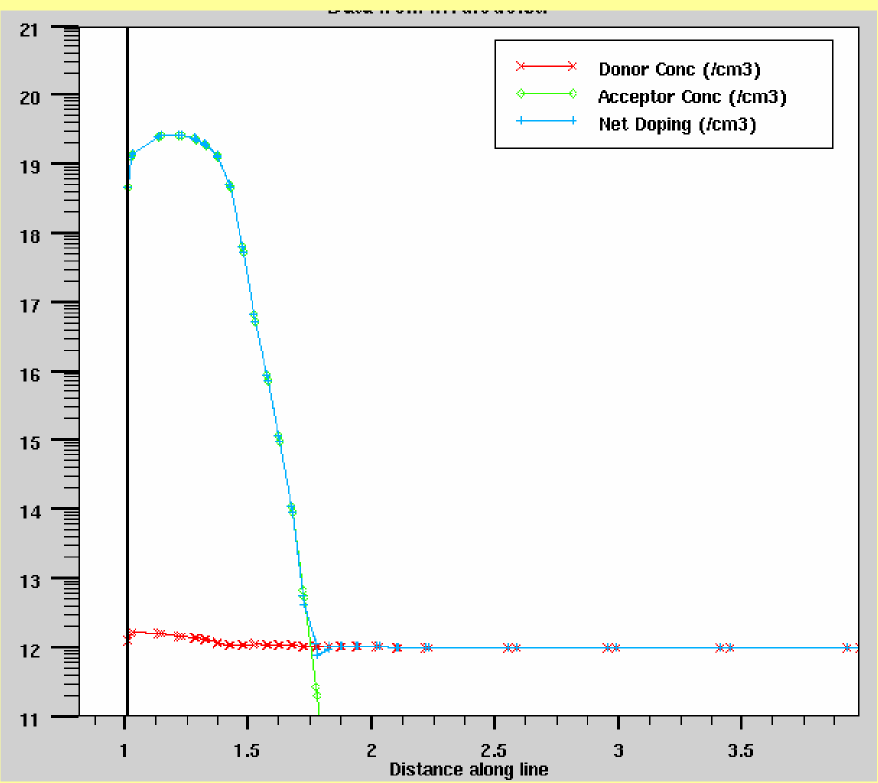
- extract name="gate oxide2" thickness material="SiO~2" mat.occno=1 x.val=100 datafile="invdiodo.final"

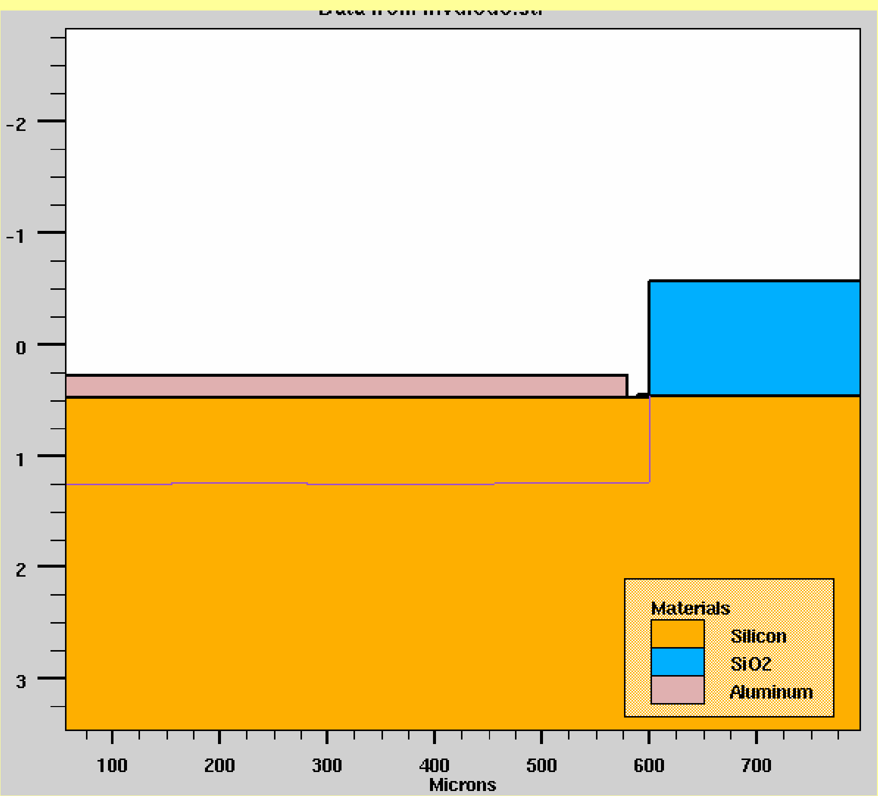
- extract name="wdif" xj material="Silicon" mat.occno=1 junc.occno=1 x.val=100 datafile="invdiodo.final"

- etch oxide left p1.x=590
- #etch oxide all
- #
- deposit alum thickness=0.2 div=3
- etch alum right p1.x=580
- #
- structure outf=invdiodo.str

- + gate oxide2=384.608 angstroms
- (0.0384608 um) X.val=100
- + wdif=0.746732 um from top of
- first Silicon layer X.val=100

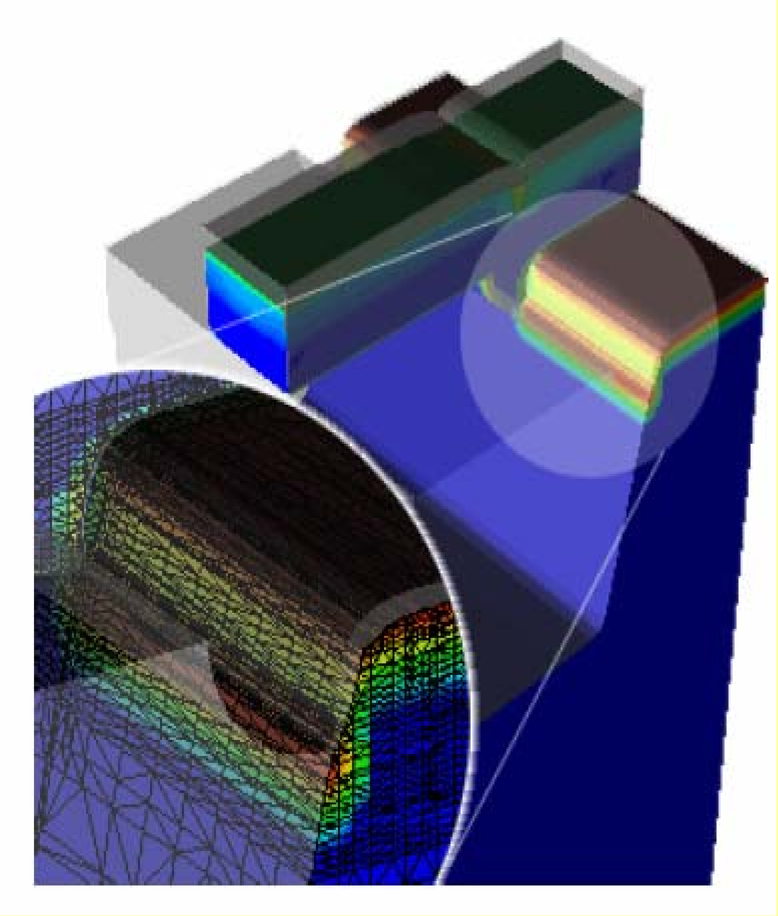
Technology Simulation: Diode





3D simulation

- **Models can be used in 3D**
- **Mesh is more complicated**
- **Some effects can only be simulated with 3D process simulation, for example:**
  - + **Narrow width effect.**
  - + **Complex implant shadowing.**
  - + **Non-rectangular gate shape after OPC effects.**
  - + **FinFET.**



Conclusions

- If it is possible, first try to simulate the critical steps on the route between theoretical design and practical realization of the device
- Process Simulator is needed: by going through all process steps you can better understand and predict final performance of the device.
- Device Simulator helps to draw final conclusions about the device performance
- Is the previous step to accurate device simulation

Device Simulation

Device simulator

- **Device simulation tools predict electrical, thermal and optical characteristics of semiconductor devices.**
- **A wide variety of devices can be modelled in one, two or three dimensions including MOSFETs, BJTs, HBTs, power devices, IGBTs, HEMTs, CCDs, photodetectors and LEDs.**
- **The most advanced physical models are commercially available, these tools allow device designs to be optimized for best performance without fabrication, eliminating the need for costly experiments.**

Device simulation benefits

- Analyze electrical, thermal and optical characteristics of your devices through simulation without having to manufacture the actual device.
- Determine static and transient terminal currents and voltages under all operating conditions of interest.
- Understand internal device operation through potential, electric field, carrier, current density, recombination and generation rate distributions.
- Optimize device designs without fabrication and find ideal structural parameters.
- Investigate breakdown and failure mechanisms, such as leakage paths and hot carrier effects.
- Generate data for compact model generation to allow analysis of circuit designs before processing.

Simulation features

- Simulation of arbitrarily shaped 1D, 2D and 3D structures.
- Consistently solves Poisson's equation, the electron and hole current continuity equations, the electron and hole energy balance equations, and the lattice heat equation.
- Steady state, transient and AC-small signal analysis with automatic I-V curve tracing and time-step algorithms.
- Ray tracing to simulate transmission, reflection and refraction across interfaces, as well as absorption and emission.
- Advanced adaptive mesh generation, which provides optimal grids with excellent solution and structure resolution using a minimum number of mesh points.
- Arbitrary doping from analytic functions, tables and process simulation.

Simulation features

- Supports multiple materials such as Si, Ge, GaAs, SiGe, AlGaAs, InP, InGaAs, InGaAsP and SiC, as well as arbitrary user-defined materials (CdTe, CdZnTe).
- Optional physical model and equation interface, which allows a user to define and solve new physical models and partial differential equations.

Device Models

- Complete set of device simulation models, including SRH and Auger recombination models, bandgap narrowing, Fermi-Dirac and Boltzman statistics and gate current.
- Extensive choice of mobility models including the Philips Unified, Lombardi Surface, Shirahata, Lucent, Inversion and Accumulation layer and composite-specific mobility models.
- Mobility dependencies on impurity concentration, lattice temperature, carrier concentration, carrier energy, parallel and perpendicular electric fields and mole fraction.
- Fowler-Nordheim, hot-carrier, band-to-band and direct tunneling models.
- Complete set of breakdown models, including stress dependent leakage current and carrier temperature dependent impact ionization.

Device Models

- Quantum mechanical models including the van Dort model, the modified local density approximation (MLDA) and a Schrodinger equation solver.
- One or several physically modeled devices can be connected in a circuit with passive components and active devices with compact models (Hspice, BSIM3).

Device Simulation: Diode

- go atlas
- mesh INF=invdiodo.str cylindrical

- #Polarización del Diodo
- #polarizado a la difusion
- electrode name=anode number=1 top
- electrode name=cathode number=2 bottom

- models consrh conmob auger fldmob bbt.std
- #models bipolar bbt.std print
- impact

- method newton climit=1e-4

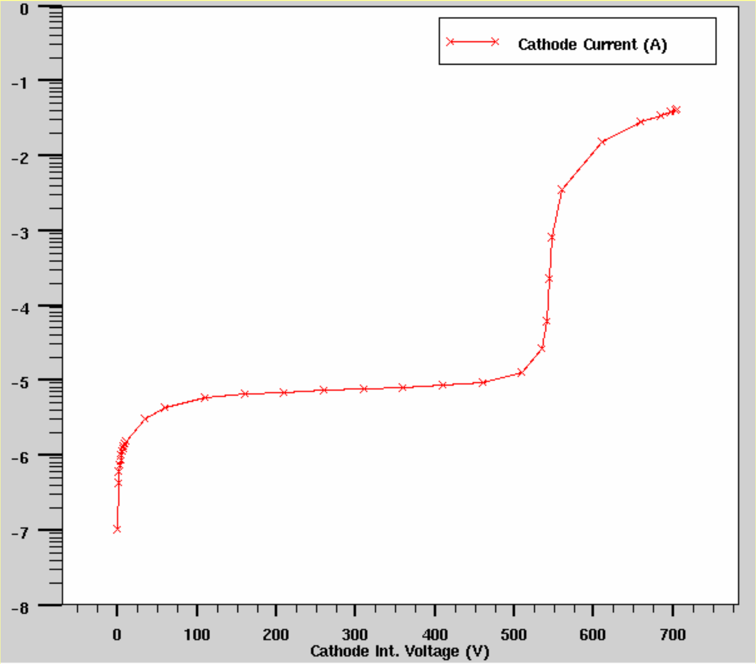
- solve init

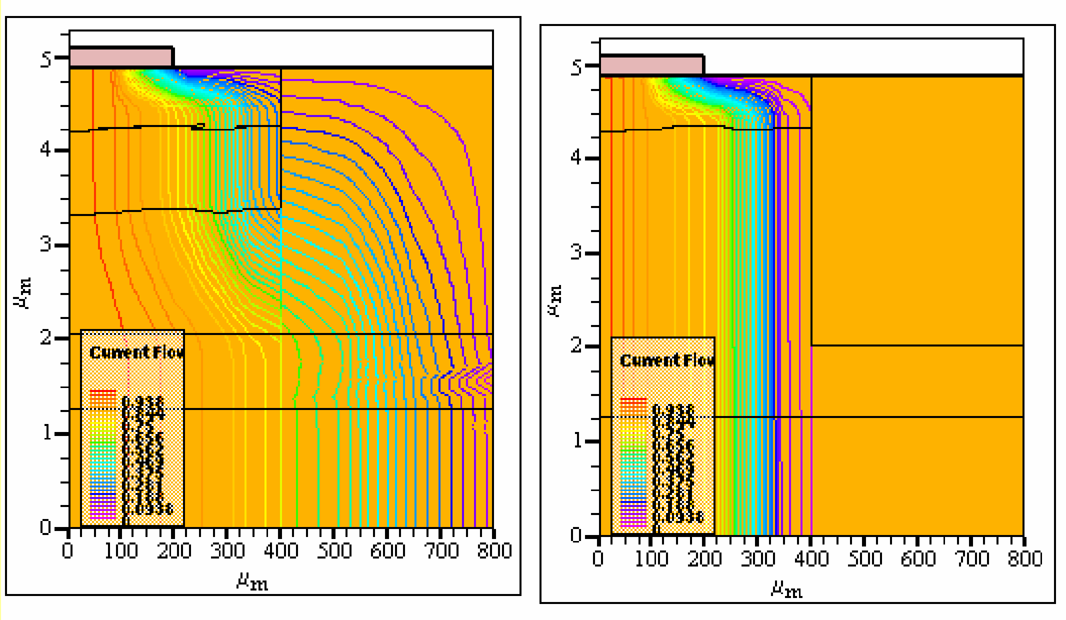
- log outf=invdiodo.log
- solve vcathode=0.1 vstep=1 vfinal=10 name=cathode
- solve vstep=50 vfinal=1800 name=cathode

- curvetrace curr.cont end.val=0.02 /
- contr.name=cathode mincur=1e-12 /
- nextst.ratio=1.1 step.init=0.1
- solve curvetrace

- quit

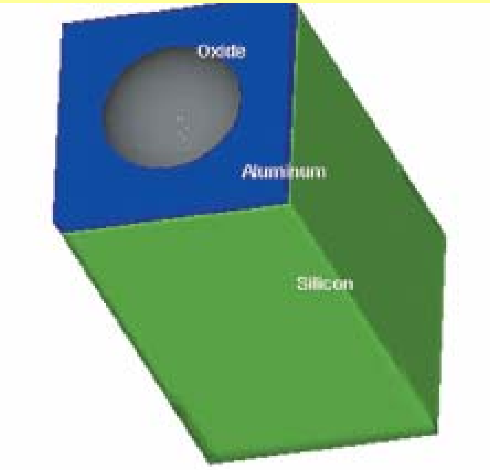
Device Simulation: Diode

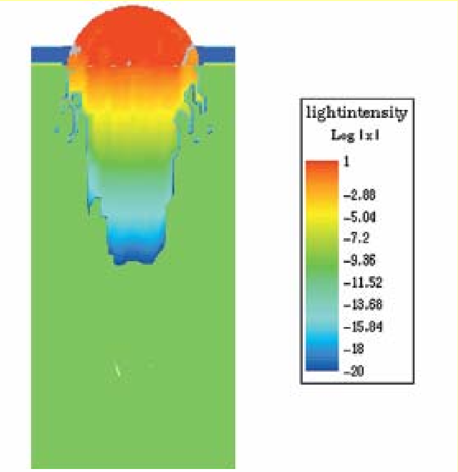




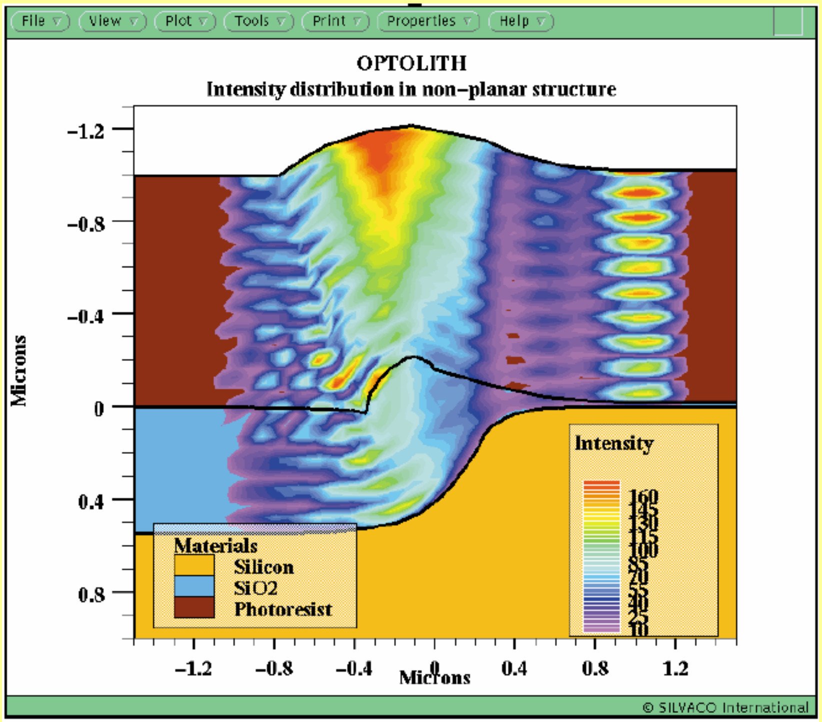
Optical interactions

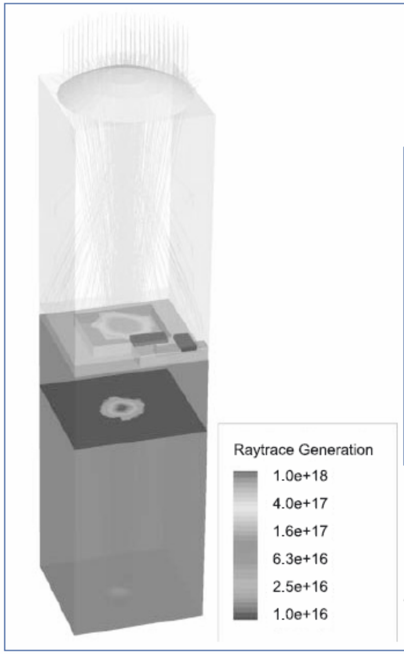
- Light refraction/reflection
- Light-matter interaction
- e-h pair generation





side the device.





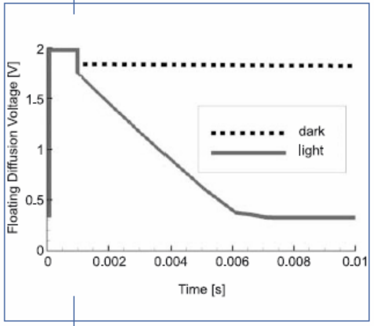
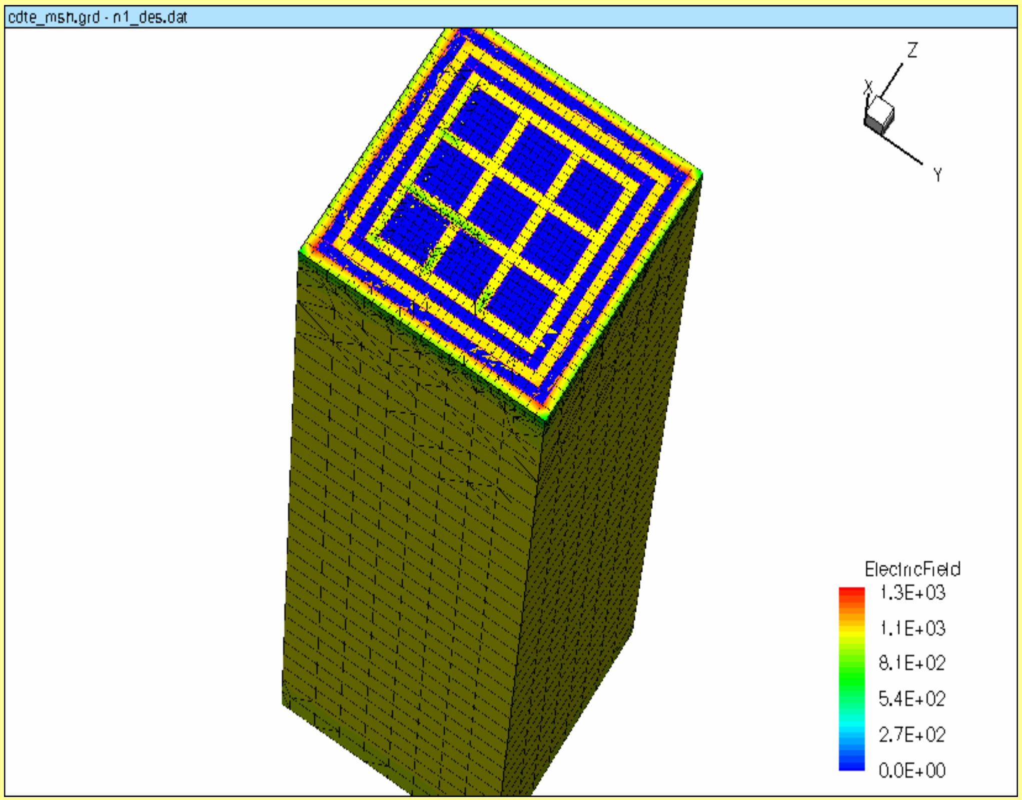
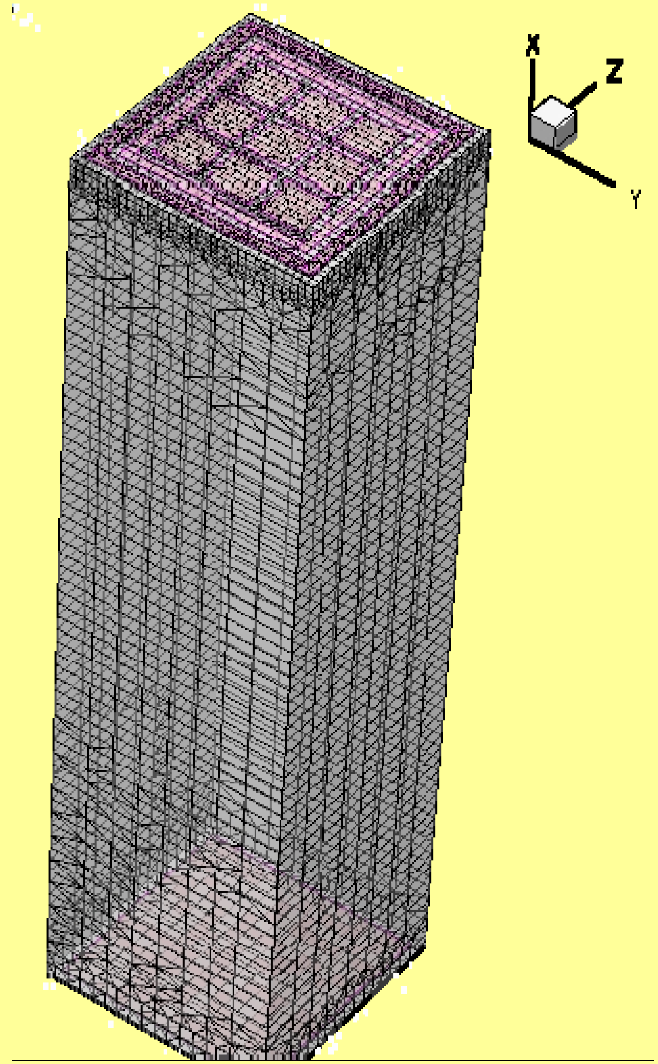


Figure 3: Floating diffusion voltage drop during illumination of pixel with a wavelength of 600 nm and a power of 0.1 mW/cm² compared with pixel not illuminated (dark)

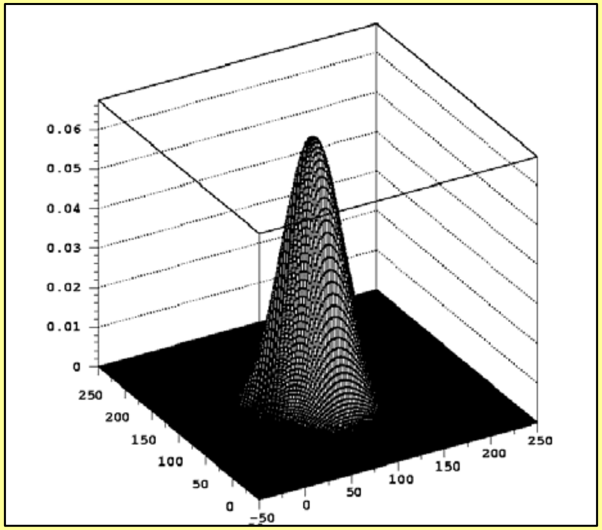
3D transient simulation

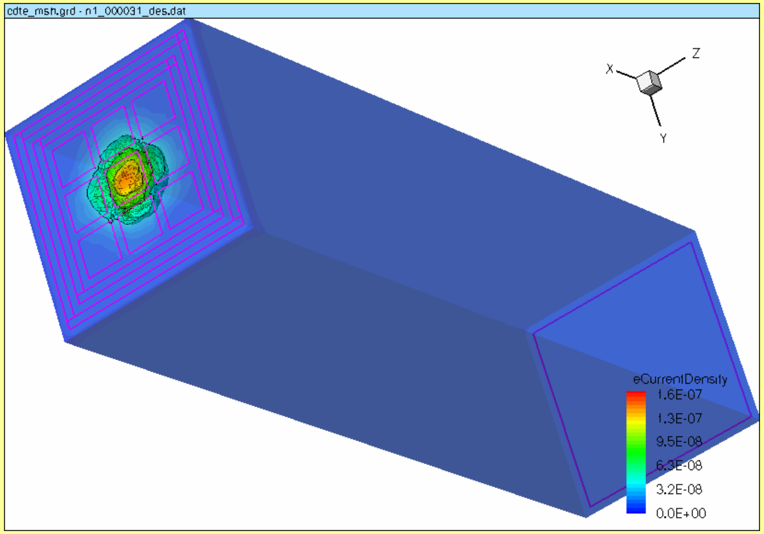
- **Example: charge collection after x-ray interaction**

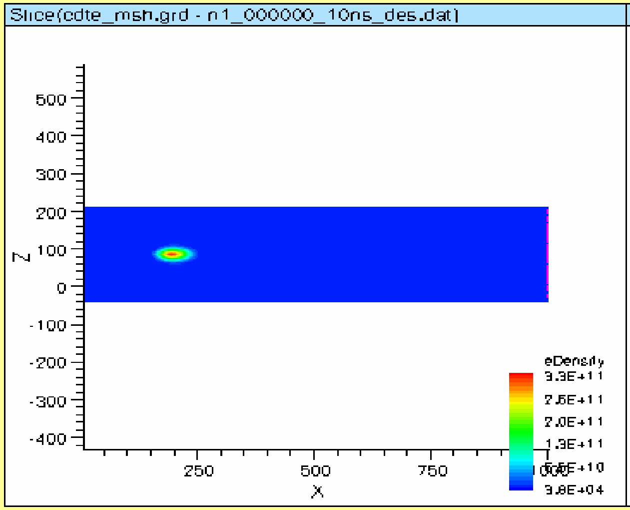


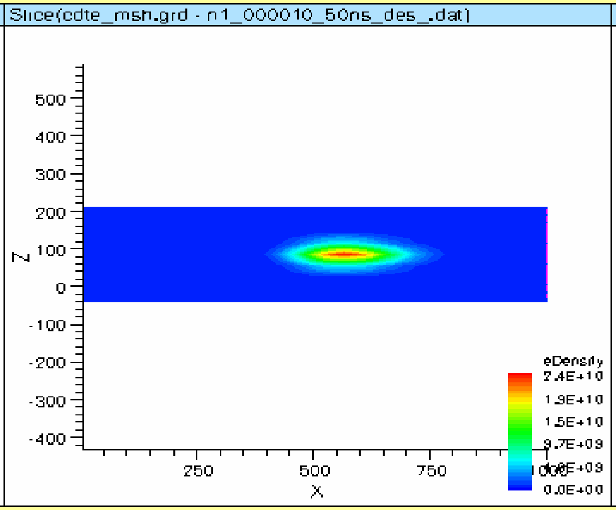


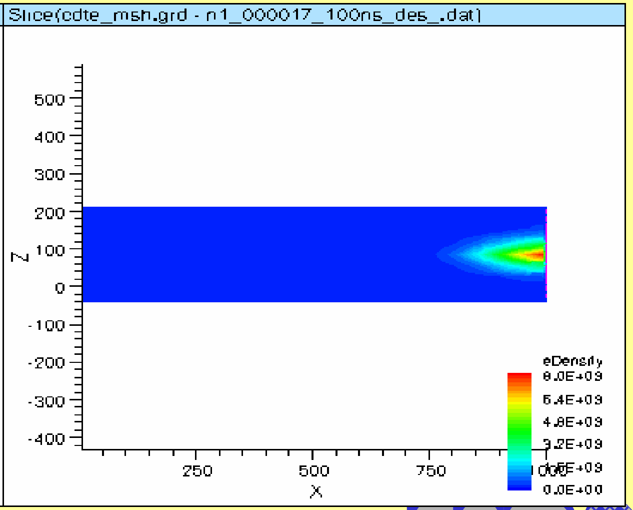
3D transient simulation





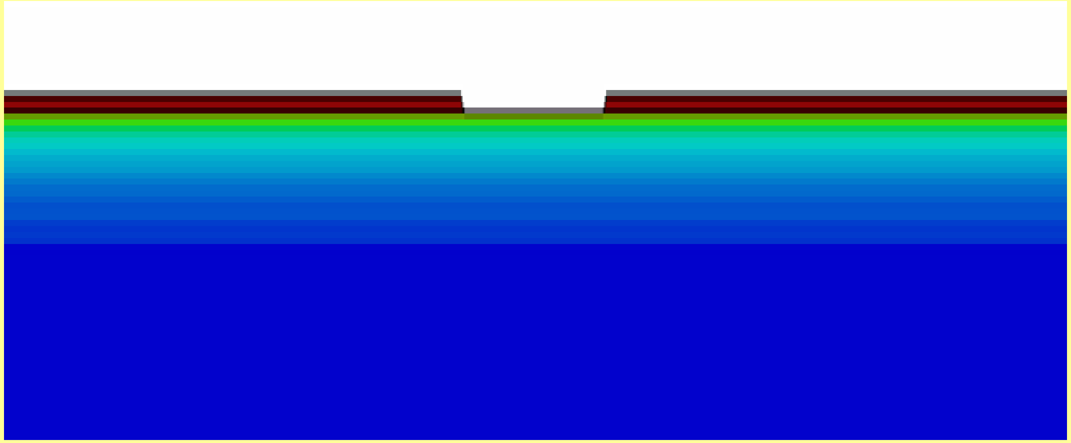




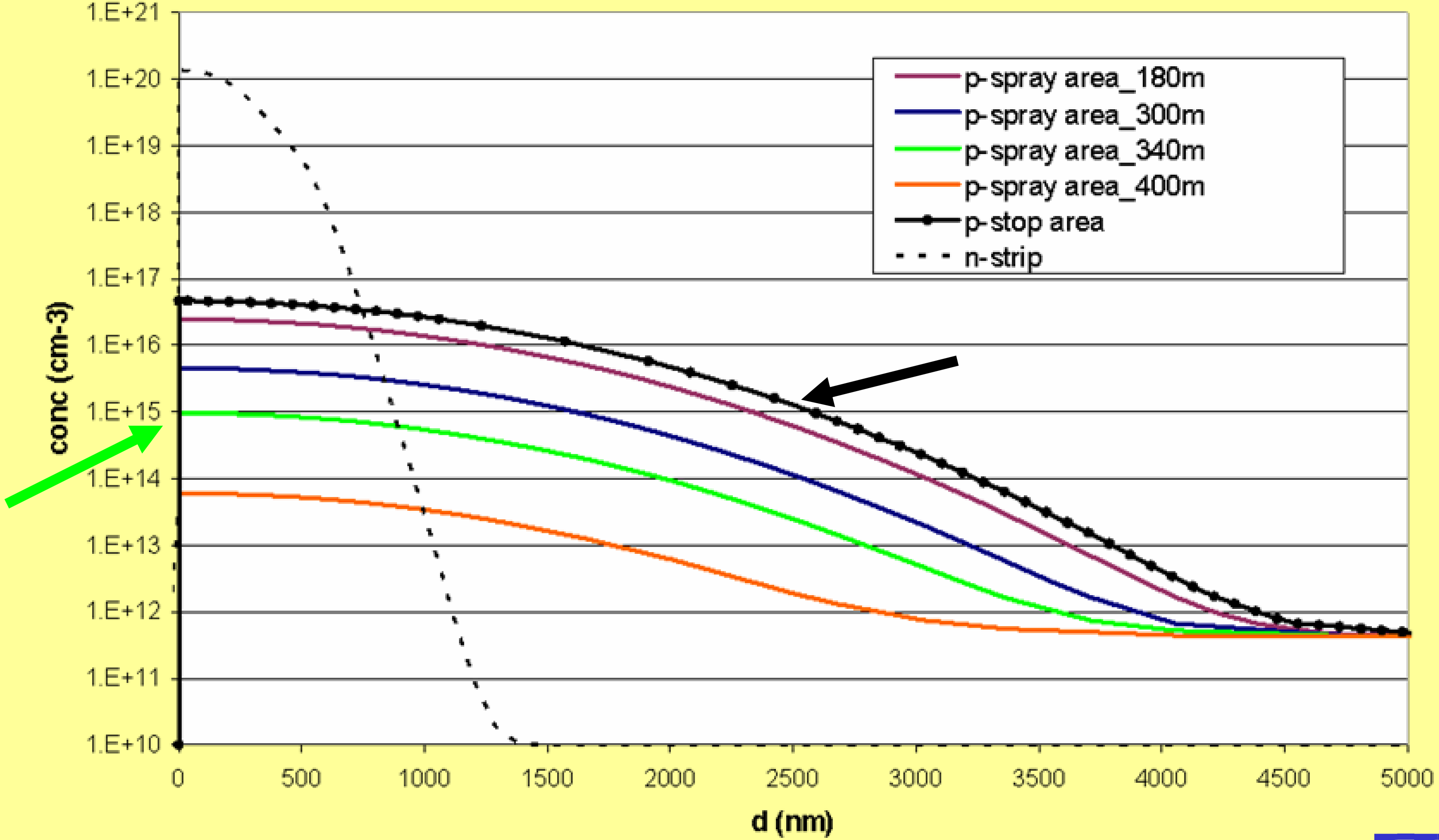


Example: Technology development

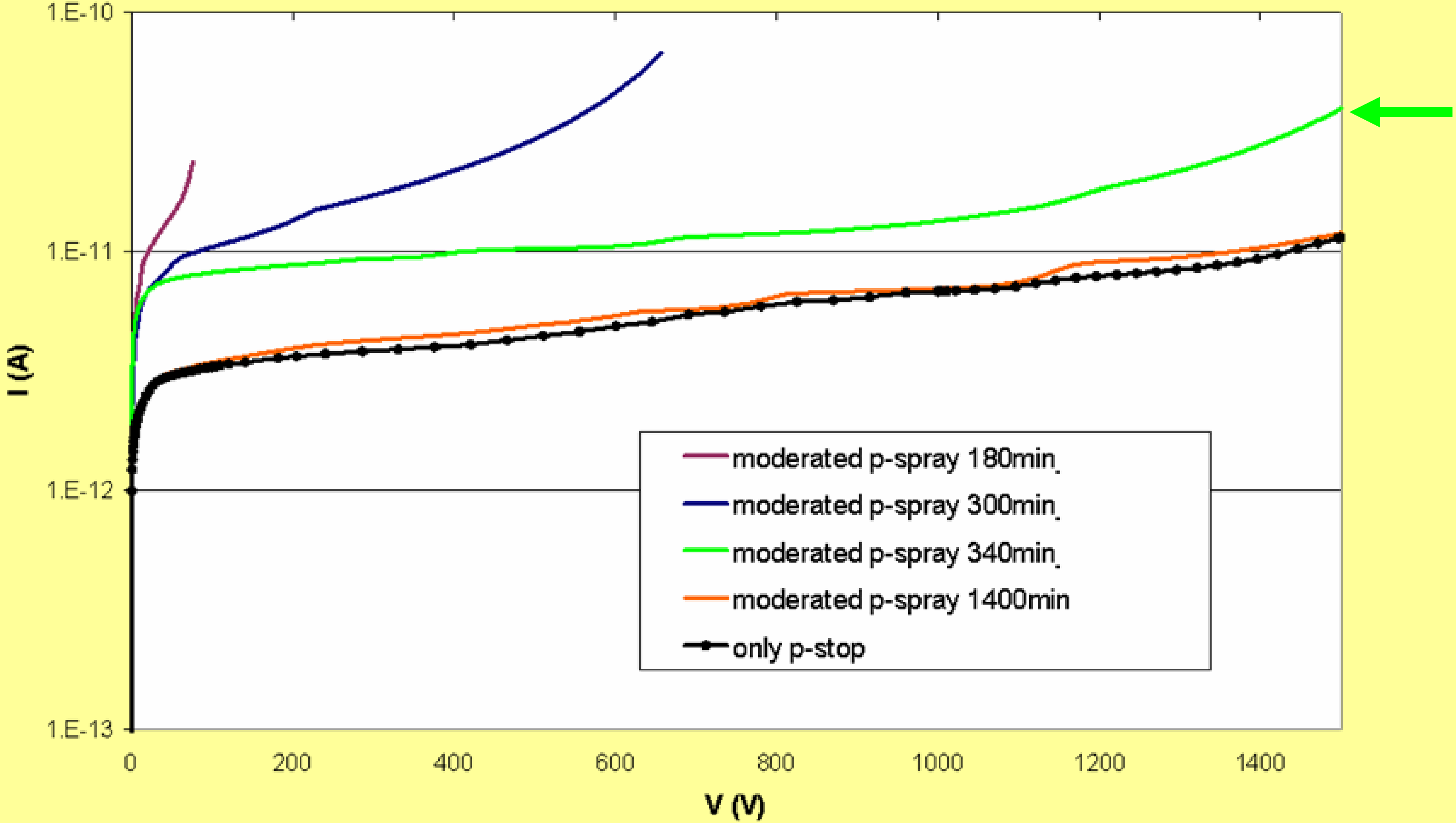
- **A process variation with respect to MPI proposal**
  - First: oxidation, photolitograpy p-stop regions, partial wet oxide etching, photoresist striping
  - At this point there are two different oxide thicknesses
    - thin oxide in the p-stop area and a thicker oxide on the rest of the silicon surface ("p-spray area")
  - P-implant (Energy 50 keV, dose 10^{13} cm^{-2})
  - Finish with the usual fabrication process



Example: Simulated doping profiles

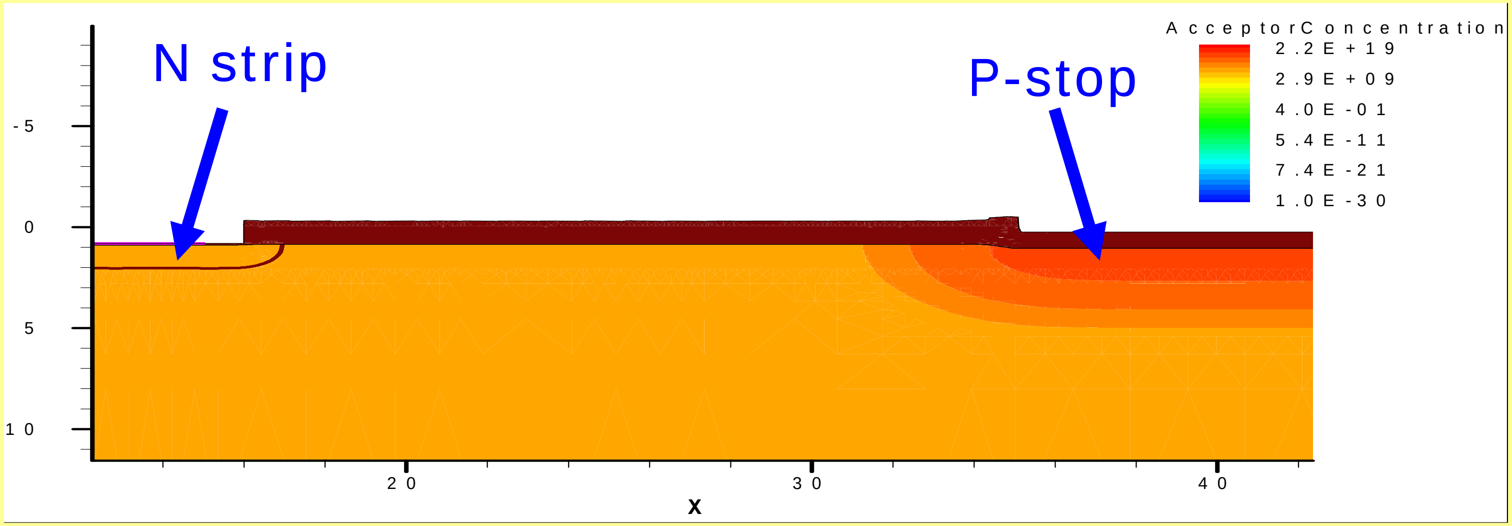


Example: Simulated breakdown voltage

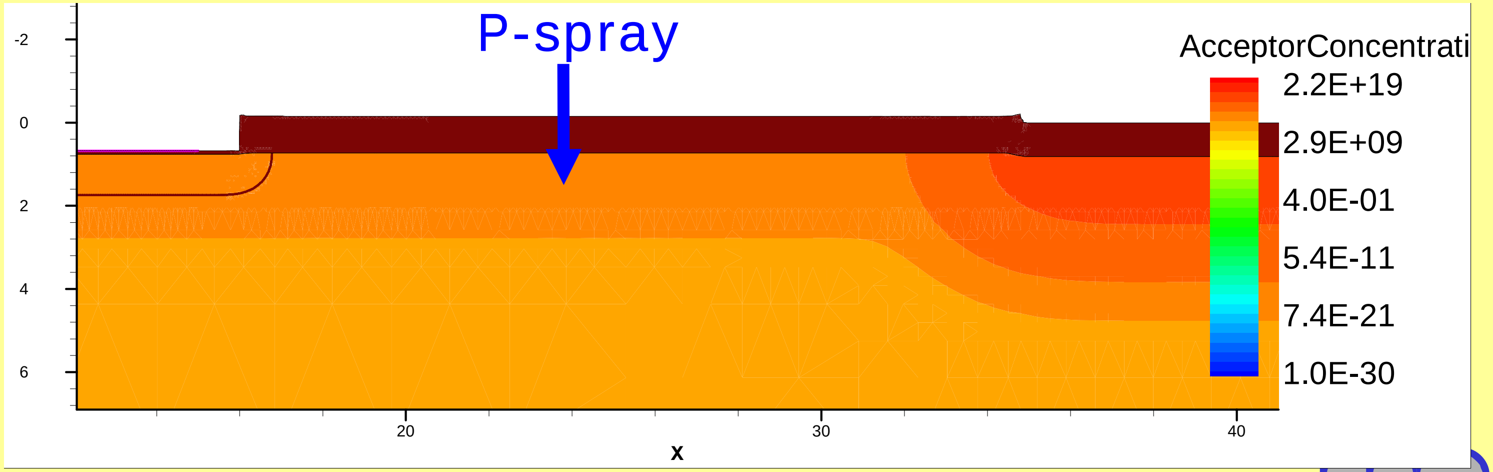


Example: Doping profile comparison

P-stop only



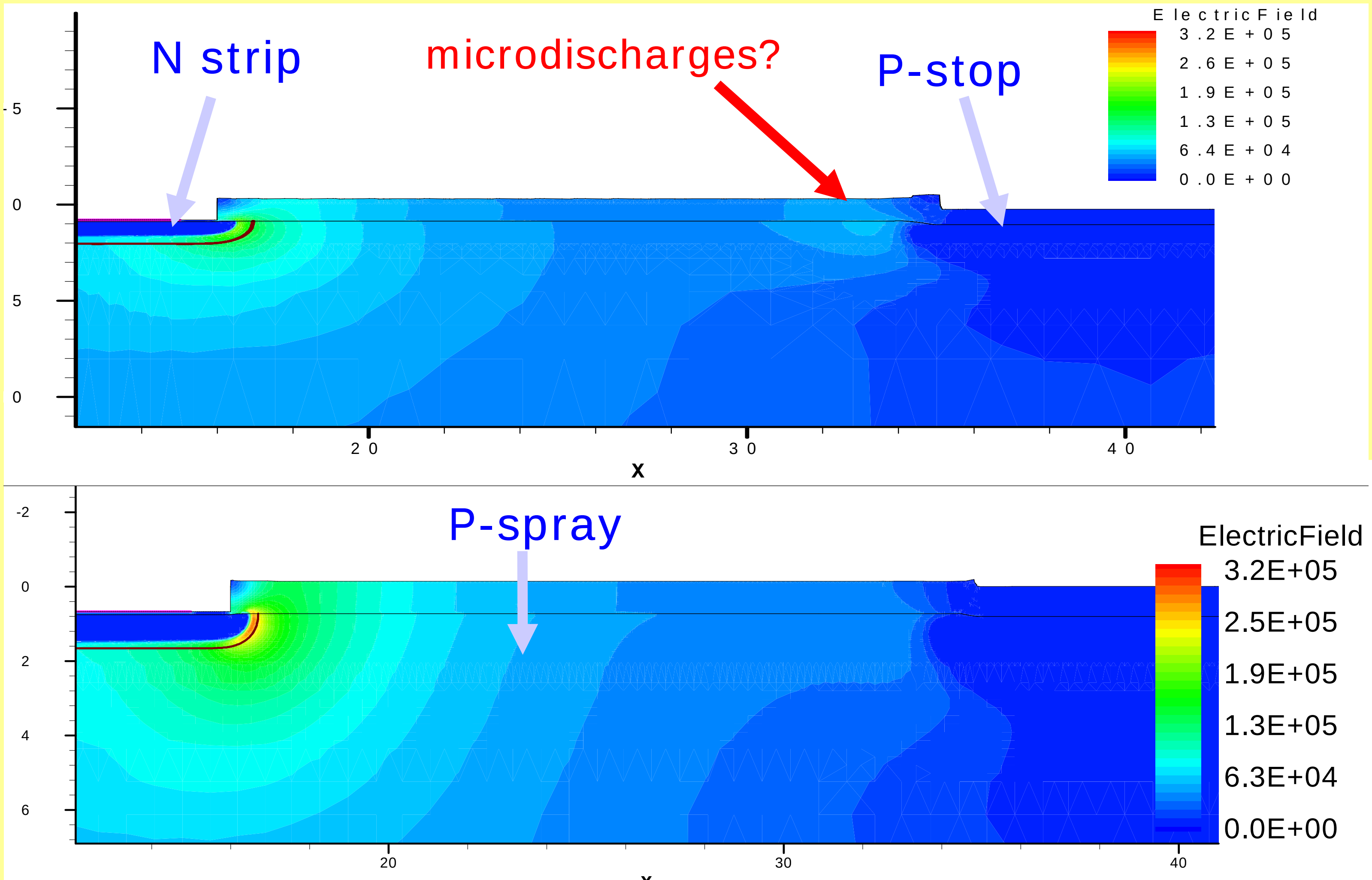
Moderated p-spray



Example: Electric field comparison

P-stop only

Moderated p-spray



Simulation of irradiated devices

- **Irradiated silicon behaves differently than standard one.**
- **As the microscopic mechanisms are not well understood, it is difficult to properly simulate irradiated devices.**
- **Two main effects:**
  + **Oxide (or dielectric in general) charge build up**
    - **Very fast effect, seem to saturate, relatively easy to incorporate to simulator**
  + **Bulk damage**
    - **Incorporation of new levels in the bandgap**
    - **Not clear values**
    - **Peruggia people (G.U.Pignatel, M.Petasseca) are developing different models**
  + **Annealing effects still pending**

Simulation of irradiated devices

- **Damage modelling**
  - + Deep levels: E_t, σ_n and σ_p
  - + SRH statistics
  - + Uniform density of defect concentration
- **Radiation damage effects to simulate:**
  - + The increasing of the Leakage Current
  - + The increasing of the Full Depletion Voltage
  - + The decreasing of the Charge Collection Efficiency

Radiation effects in Sentaurus

- Sentaurus Device can simulate the degradation of semiconductor devices due to received radiation.
- For now, this degradation is modeled as a change of trapped charge, which may cause a shift in device characteristics.
- Usually, degradation is important in insulators (for example, oxide) and users should define these insulators as wide band-gap semiconductors so that the appropriate transient trap equations can be solved inside these regions.

- SEU effects due to alpha and heavy ions are also incorprated natively in Sentaurus Device

N-type 3-Levels Radiation Damage Model

- **N-type silicon is more or less understood, and a three level model works fine**

Type	Defect	Energy	σ_n	σ_p	η
Acceptor	V2	E_c-0.42	2.2e-15**	1.2e-14	13
Acceptor	V2O ?	E_c-0.50	4e-15**	3.5e-14	0.08**
Donor	C_iO_i	E_v+0.36	2e-18**	2.5e-15**	1.1**

*D. Passeri, P. Ciampolini, G. Bilei and F. Moscatelli, IEEE Trans. Nucl. Sci., vol. 48, pp. 1688-1693, 2001.

** M. Moll, Ph.D. Thesis, Hamburg University, 1999, DESY-THESIS-1999-040, ISSN-1435-8085

P-type 2-Levels Radiation Damage Model

Level**	Ass.	σ_n [cm^{-2}]	*σ_p [cm^{-2}]	η [cm^{-1}]
E_c-0.42eV	$VV^{(-/0)}$	$2\cdot10^{-15}$	$2\cdot10^{-14}$	1.6
E_c-0.46eV	$VVV^{(-/0)}$	$5\cdot10^{-15}$	$5\cdot10^{-14}$	0.9

- (**) Levels selected from:
  - M. Ahmed, et al., Nuc. Instr. And Meth A 457 (2001) 588-594
  - S.Pirolo et al., Nuc. Instr. And Meth. A 426 (1996) 126-130

- Two levels model is able to reproduce static characteristics (current and depletion voltage) of irradiated diodes
- This model is unable to reproduce the experimental Charge Collection Efficiency (CCE) of irradiated devices
- Hole cross section values are a best fit rather than physical
  - One or two order of magnitude bigger than measurements

P-type 3-Levels Radiation Damage Model

- Introduction of a donor level very important for Charge Collection (CC) simulations
- the donor defect level allows to reproduce the experimetal data.

Level	Ass.	σ_n [cm^{-2}]	σ_p [cm^{-2}]	η [cm^{-1}]
E_c-0.42eV	$VV^{(-/0)}$	$2 \cdot 10^{-15}$	*$2 \cdot 10^{-14}$	1.613
E_c-0.46eV	$VVV^{(-/0)}$	$5 \cdot 10^{-15}$	*$5 \cdot 10^{-14}$	0.9
E_v+0.36eV	? C_iO_i?	$2.5 \cdot 10^{-14}$ (exp)	$2.5 \cdot 10^{-15}$ (exp)	0.9

- no changes for the Vdep and Leakage Current due to the donor defect level:
  - α (simulated)= 3.8·10-17 A/cm
  - β (simulated) =(4.0 ±0.1) ·10-3 cm-1

Other tools: Structure editor

- **Allows device structure description without the need of process simulator**
- **Different operational modes:**
  - + **2D structure editing, 3D structure editing, and 3D process emulation. Geometric and process emulation operations can be mixed freely,**
- **Powerful visualization.**
  - + **Structures are displayed as they are created and view filters make it possible to select a subset of regions and to make regions transparent.**

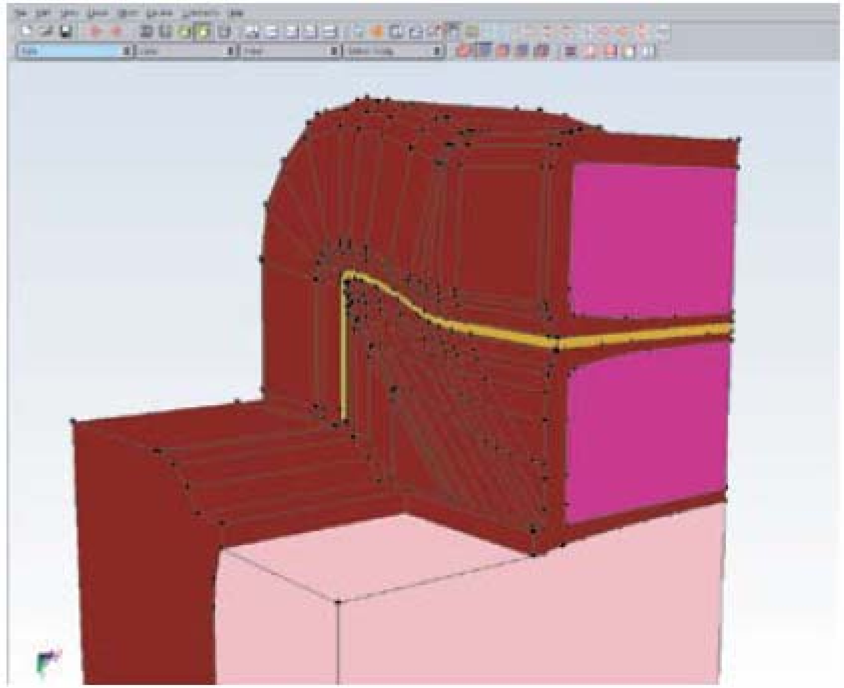


Figure 1. Main graphical user interface of Sentaurus Structure Editor.

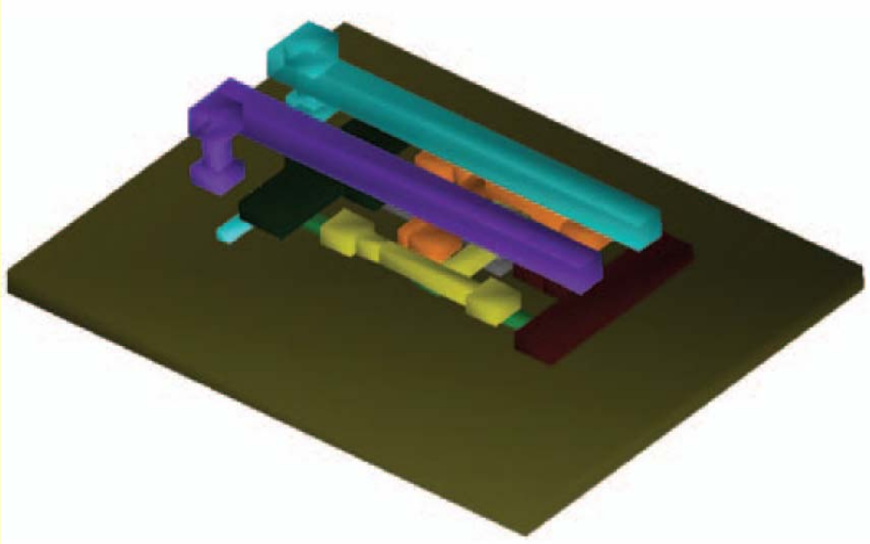
Other tools: Process emulator

- Three-Dimensional Process Emulator
- Part of structure editor
- Process emulation Editor translates processing steps, such as etching and deposition, patterning, fill and polish, into geometric operations.
- Support forvarious options such as isotropic and anisotropic etching and deposition, rounding, and blending to account for specific processing effects.
- External layout files in CIF or GDSII format can be imported into the Editor

- Use of analytical models instead of process simulator reduces development time at the expense of accuracy

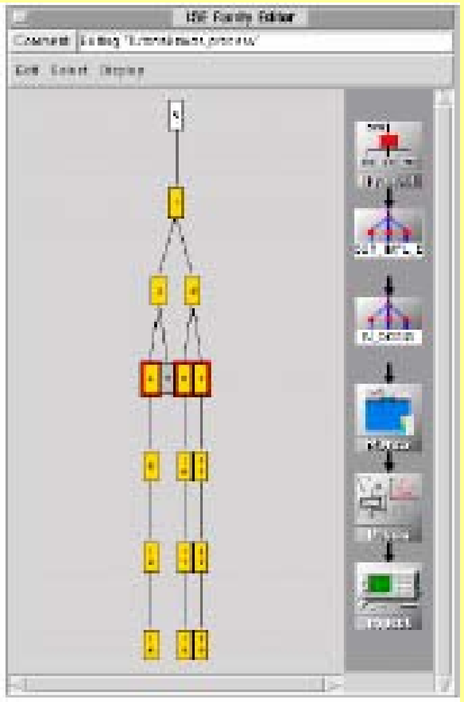
Other tools: Interconnect Analysis

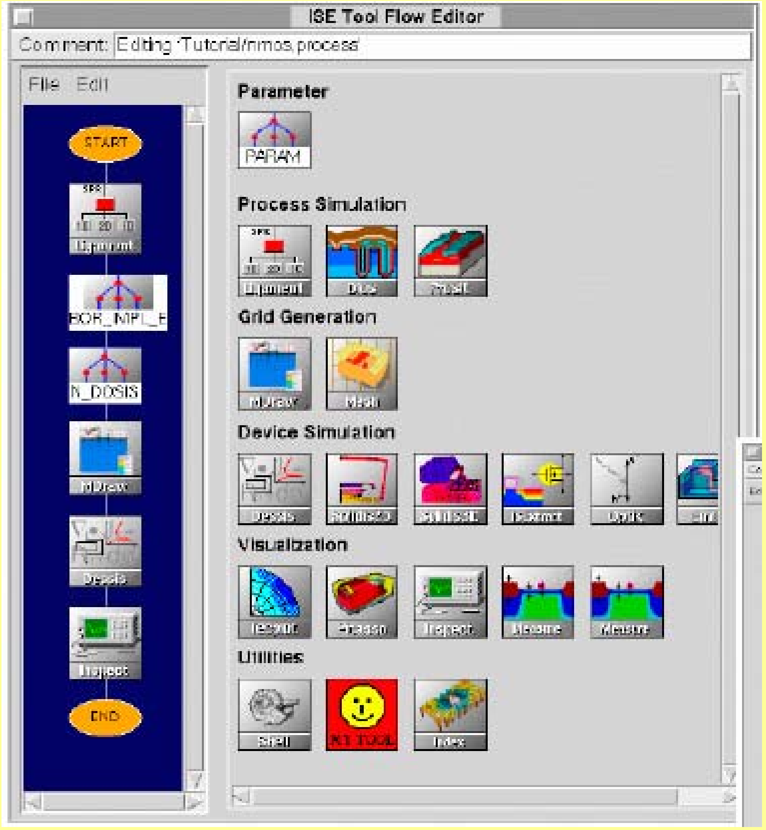
- Collection of 2D and 3D field solvers and interfaces for interconnect analysis and modeling designed to simulate the electrical and thermal effects of complex on-chip interconnect.
- The performance of DSM technologies is dominated by parasitic capacitance, resistance, and inductance of the interconnect structures.
- Critical design issues –timing, power, noise and reliability– require accurate and robust interconnect models.
- Simulation and extraction of interconnect capacitance, resistance, and inductance using field solvers and interfaces.
- SPICE netlist generation



Other tools: Workbench

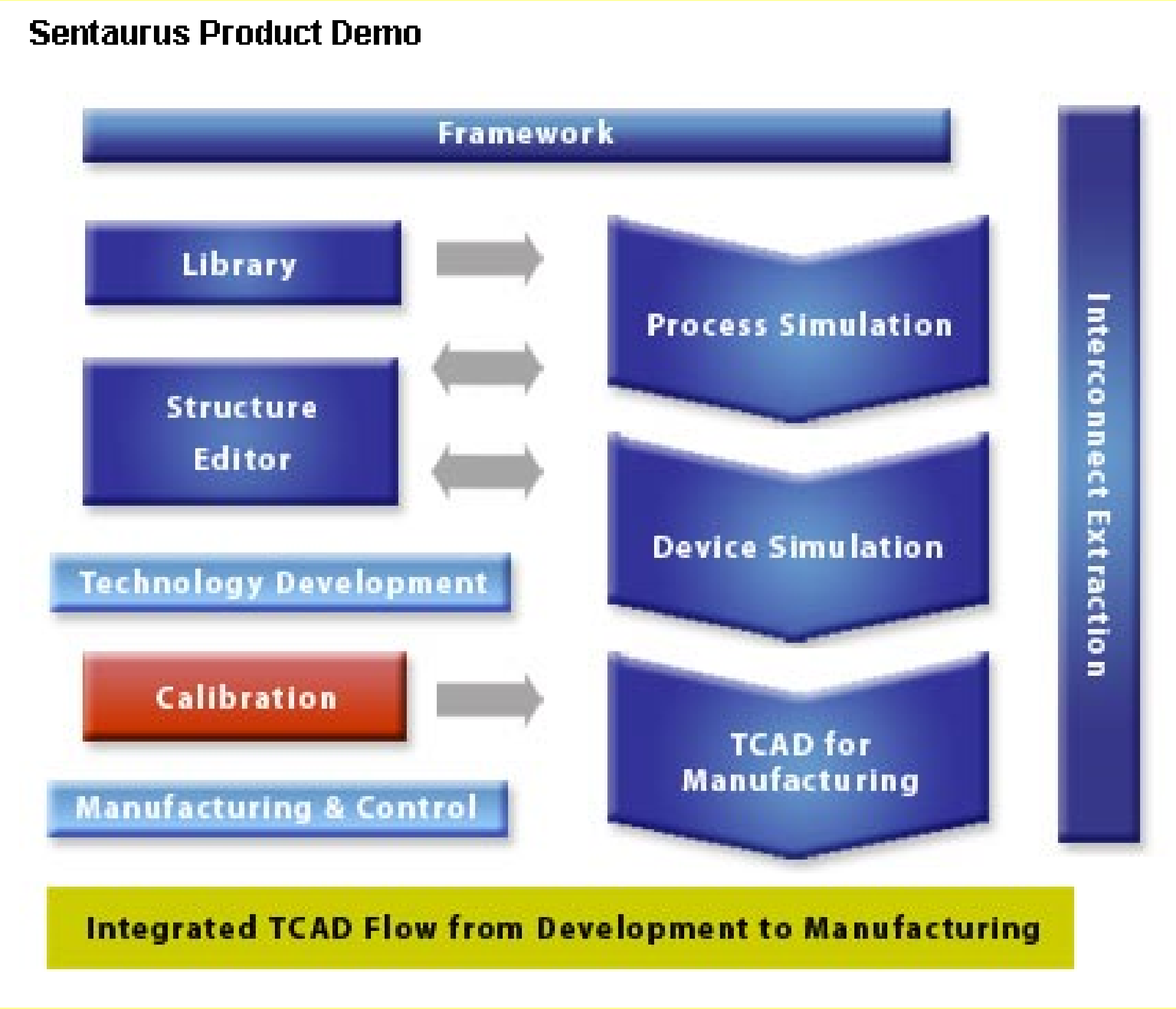
- Software vendors provide with graphic interface for creating, managing, executing and analyzing process and device simulations
- Allow parameterization, repeating the simulations for different values
- Use of process recipe libraries
- Automatic Design-of-Experiment (DoE) generation and analysis (Response Surface Modelling)
- Automatic parameter optimization
- Batch and queuing control
- Link to visualization tools





Synopsis Sentaurus

- From Synopsis
- Merge of
  + TMA
  + ISE-TCAD
- Suppose to be the best of both worlds



Synopsis Sentaurus

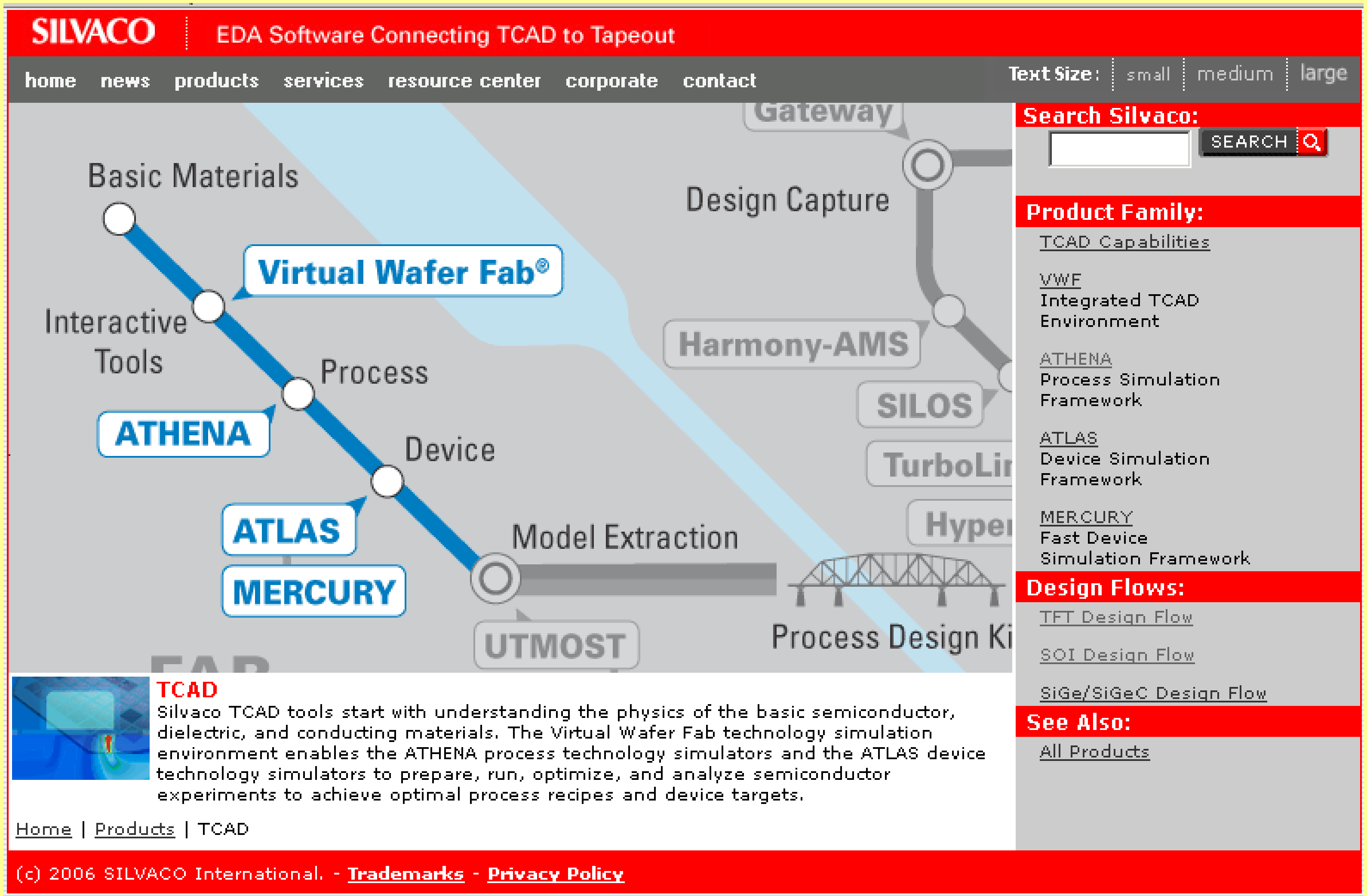
SYNOPSYS®

TCAD Sentaurus

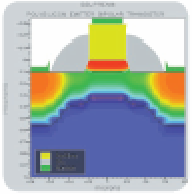
Framework	Process Simulation	Device Creation	Device Simulation	Reference Material
Sentaurus Workbench	Sentaurus Process	Sentaurus Structure Editor	Sentaurus Device	Sentaurus Applications Library
Calibration Kit	Advanced Calibration	DIP	Compact Models	Dios
Inspect		Mesh	Sentaurus Device EMW	Mdraw
Ligament		Noffset3D	Sentaurus Device Monte Carlo	SXtract
Optimizer			Solvers	
Sentaurus Data Explorer			TED	
Tecplot SV				
Utilities				

Version X-2005.10

Silvaco TCAD

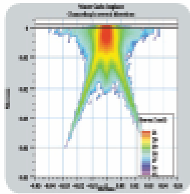


Silvaco packages



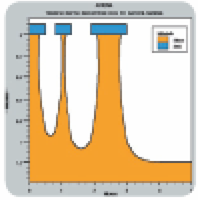
SSuprem4

2D Process Simulator



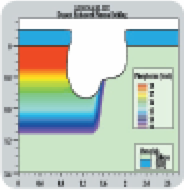
MC Implant

3D Monte-Carlo Implantation Simulator



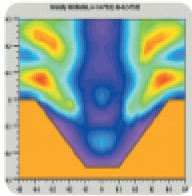
Elite

2D Etch and Deposition Simulator



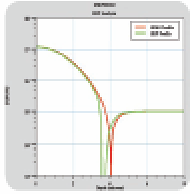
MC Etch/Depo

2D Monte Carlo Etch and Deposition Simulator



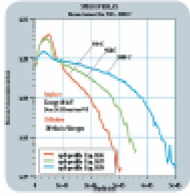
Optolith

2D Optical Lithography Simulator



SSuprem3

1D Process Simulator



SPDB

Silvaco's Process Database

ANSYS

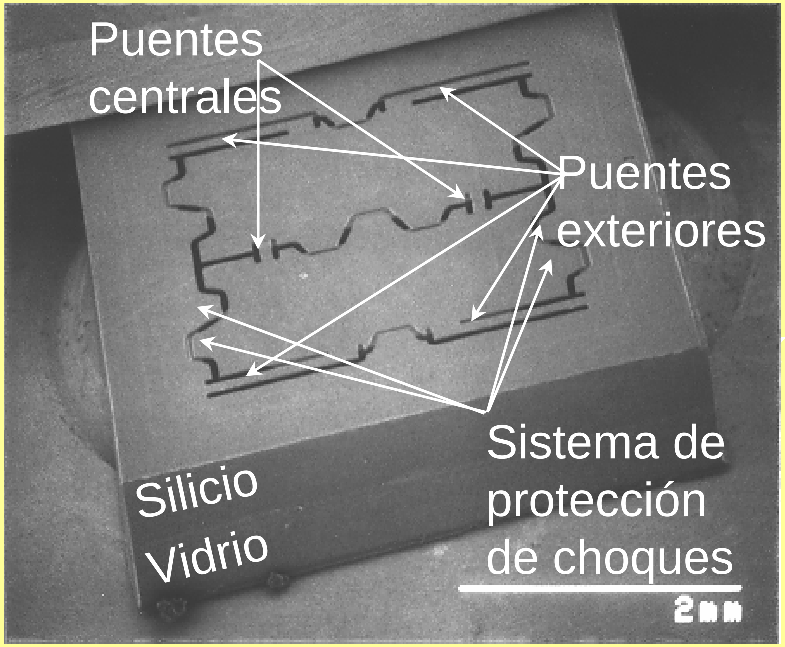
MEMS Packaging

MEMS

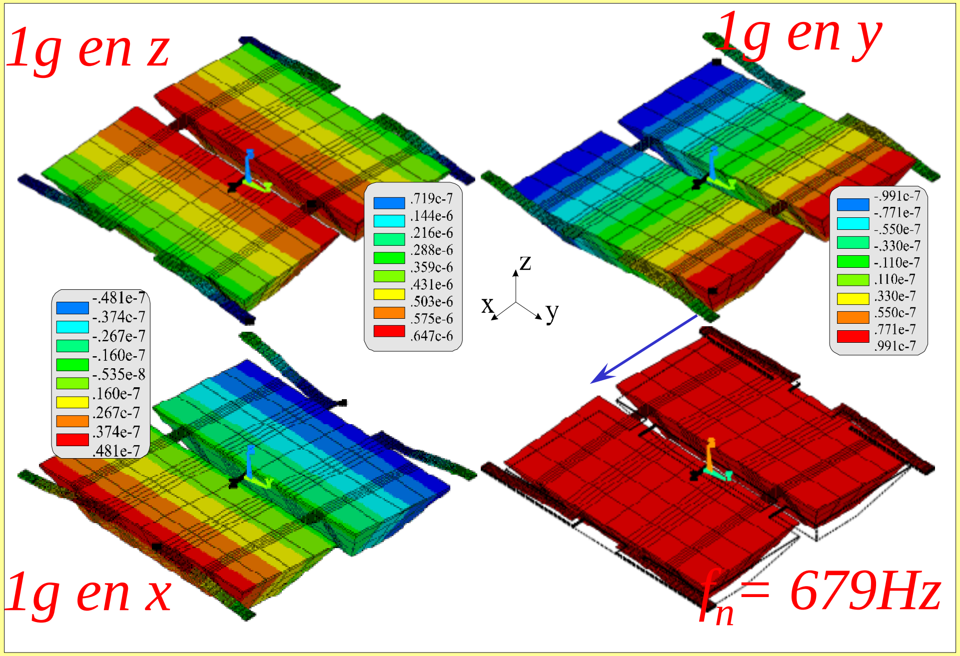
- MEMS are Micro Electro Mechanical Systems
- Are system that incorporate in the same device electrical and mechanical features
- Are fabricated using silicon micromechanization
- Usually they have mobile parts
- They present new simulation needs
  - + Mechanical, mobile parts, resonance
  - + Electrical
  - + Thermal
  - + Fluidics
  - + Physics
  - + Coupled features (electro-mechanical for example)

Design and simulation

Acelerómetro piezorresistivo triaxial simulación FEM



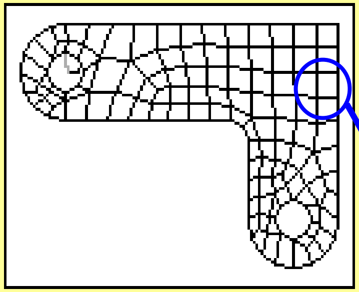
TRIAXIAL



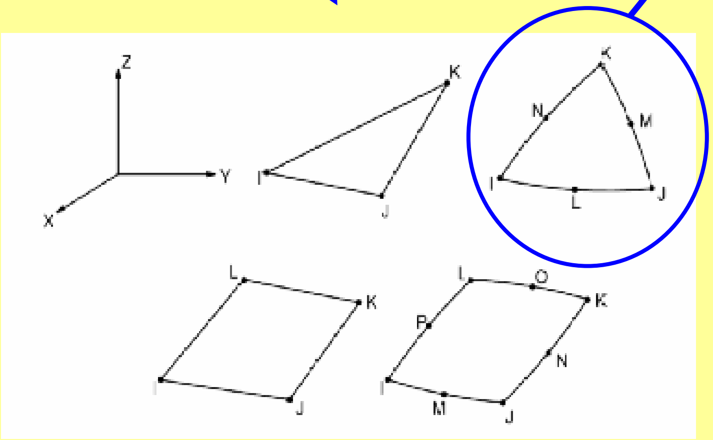
Triaxial	Sen[mV/(V*g)]	Z [µm/g]	Frec. [Hz]
z	0.855	0.647	679
y	0.097	0.099	1016
x	0.159	0.48	1419

Finite Element Modelization (FEM)

Subdivisión en elementos:

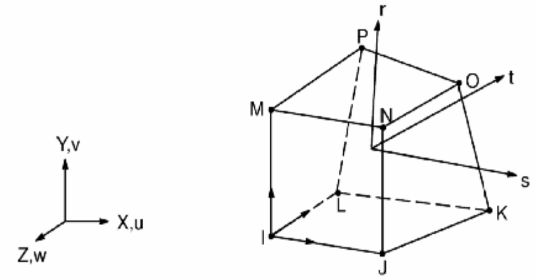


Elementos:



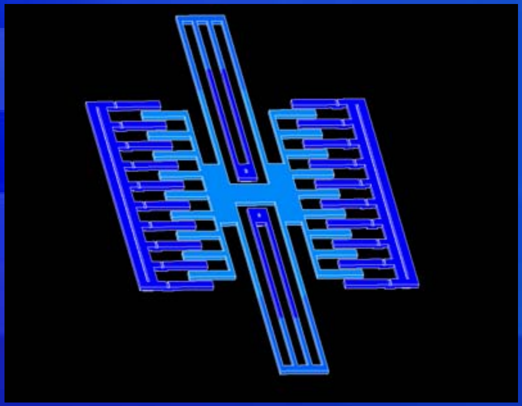
14.5 SOLID5 — 3–D Coupled Field Solid

ANSYS



Matrix or Vector	Shape Functions	Integration Points
Magnetic Potential Coefficient Matrix	Equation (12.8.18–22)	2 x 2 x 2
Electrical Conductivity Matrix	Equation (12.8.18–21)	2 x 2 x 2
Thermal Conductivity Matrix	Equation (12.8.18–20)	2 x 2 x 2
Stiffness Matrix	Equations (12.8.18–1), (12.8.18–2), and (12.8.18–3) or, if modified extra shapes are included (KEYOPT(3) = 0), equations (12.8.19–1), (12.8.19–2), and (12.8.19–3)	2 x 2 x 2
Piezoelectric Coupling Matrix	Same as combination of stiffness matrix without extra displacement shapes and conductivity matrix.	2 x 2 x 2
Specific Heat Matrix	Same as conductivity matrix. Matrix is diagonalized as described in Section 12.2	2 x 2 x 2

The ANSYS Multiphysics MEMS Initiative



Dr. Paul Lethbridge - Multiphysics Product Manager

The ANSYS Family of Products

ANSYS Multiphysics — Extreme functionality *The whole enchilada!*

ANSYS University — Educational/Non Commercial Use Products

ANSYS Mechanical — High performance mechanical & Thermal

ANSYS FLOTRAN

ANSYS Emag

Powerful tools for the physics *specialist*

ANSYS Professional

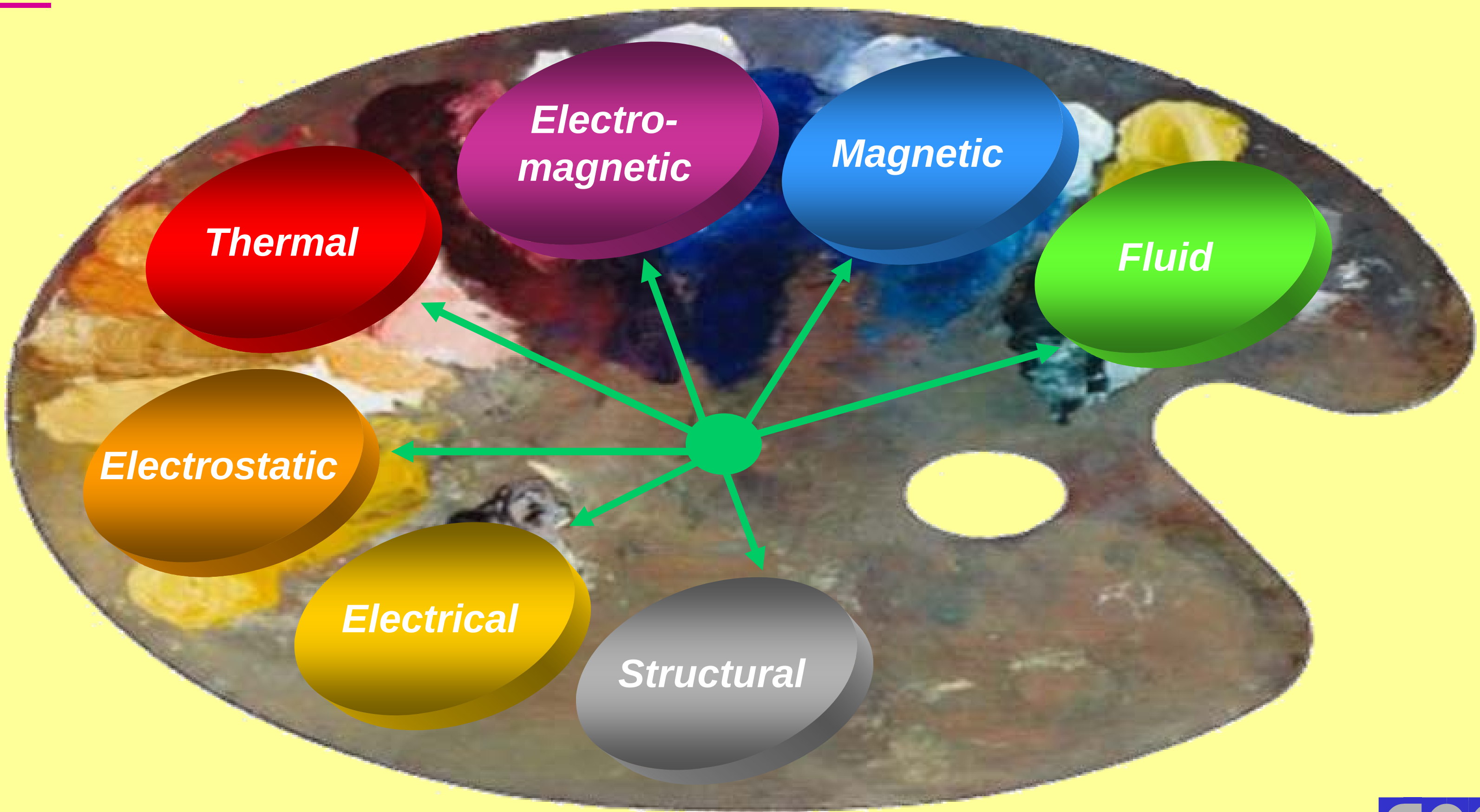
ANSYS Structural

Ease of use & Entry level capability

ANSYS MCAD & ECAD Connection products

What is ANSYS Multiphysics?

A general purpose analysis tool allowing a user to to combine the effects of two or more different, yet interrelated physics, within one, **unified** simulation environment.

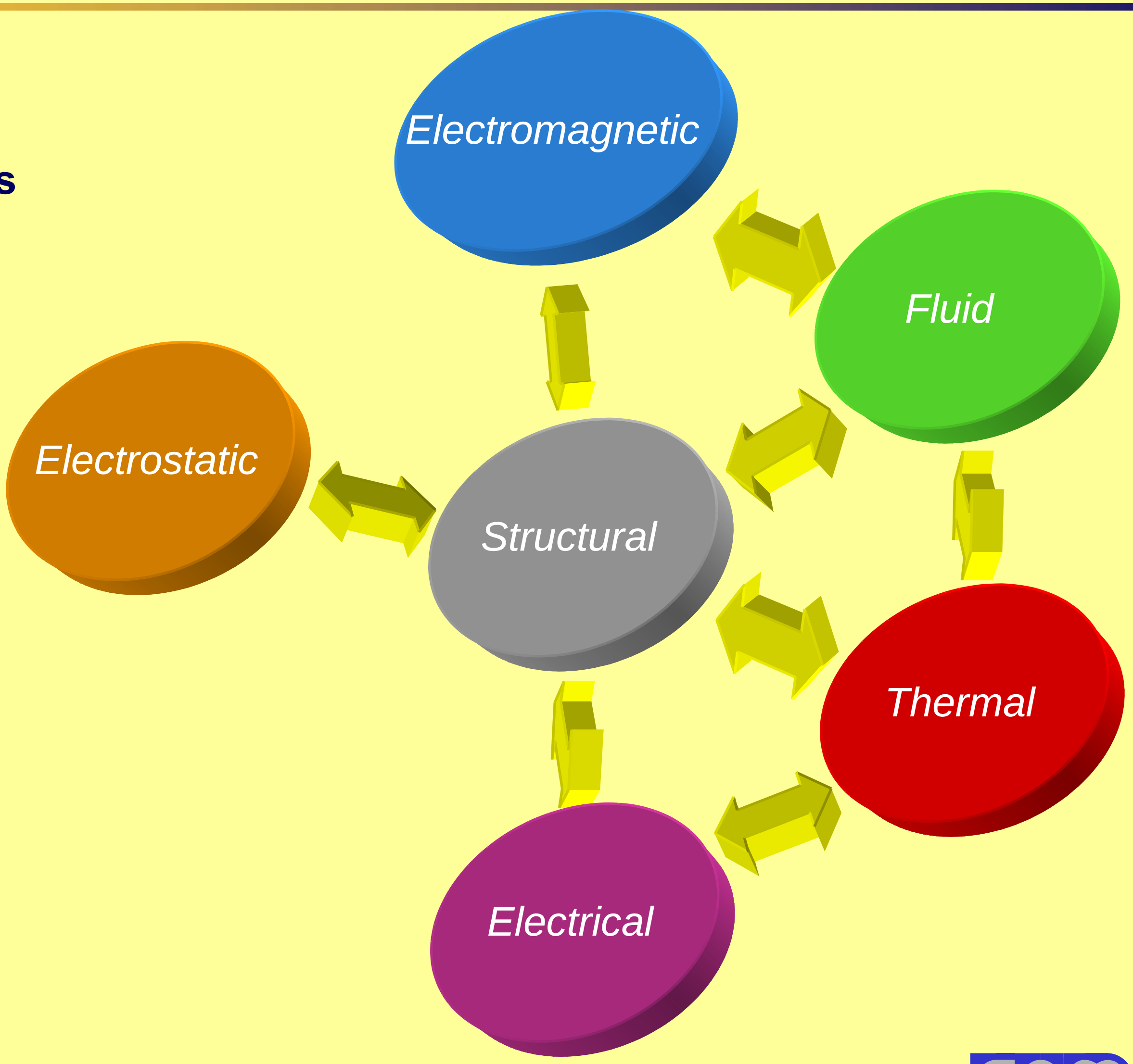


Benefits of Multiphysics

- No other analysis tool provides as many physics under one roof!
- Greatest breadth and technical depth of physics.
- Fully parametric models across physics, geometry, materials, loads.
- Perform Design Optimization across physics, geometry, materials and loads.
- Seamless integration with ANSYS Probabilistic Design System (PDS).
- Extremely sophisticated analysis capability.
- Bottom line benefits:
  - Analysis closely match reality – bringing reality to the desktop
  - Reduced assumptions that question certainty and compromise accuracy.
  - Lower cost: Fewer analysis software tools to purchase,learn & manage.
  - Lower cost: R&D process compression

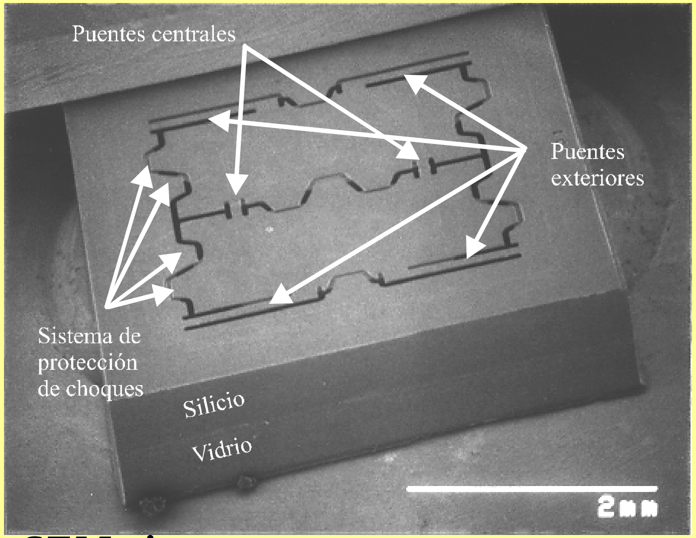
ANSYS Multiphysics
MEMS Device Applications

- Inertial Devices
- Comb & thermal Actuators
- Pressure Transducers
- RF Filters – Resonators

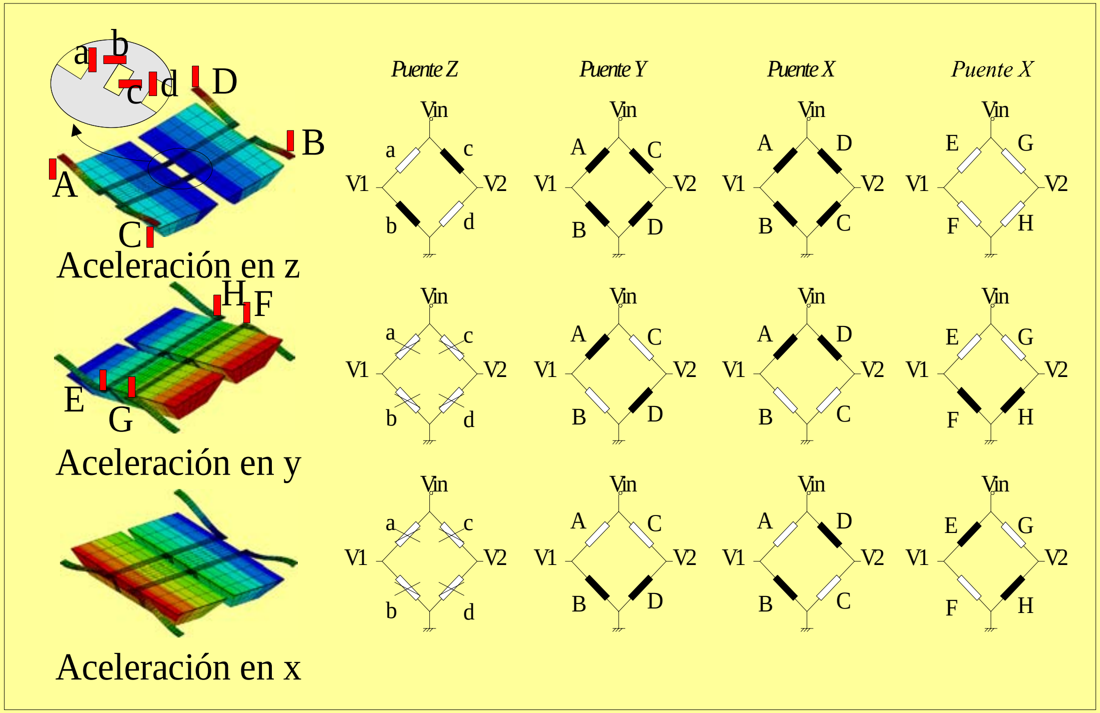


- Lab-on-a-chip
- Ink Jet printer technology
- Micromirror technology

Example: Piezoresistive accelerometer



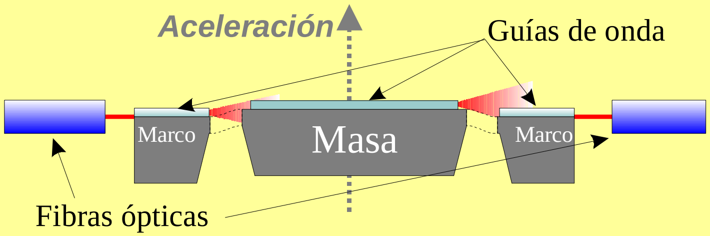
SEM picture



Demostrador

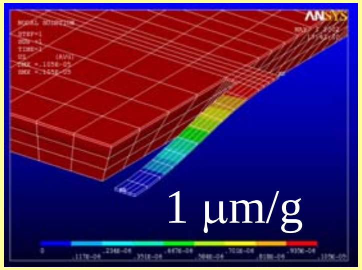
Example: Optical accelerometer

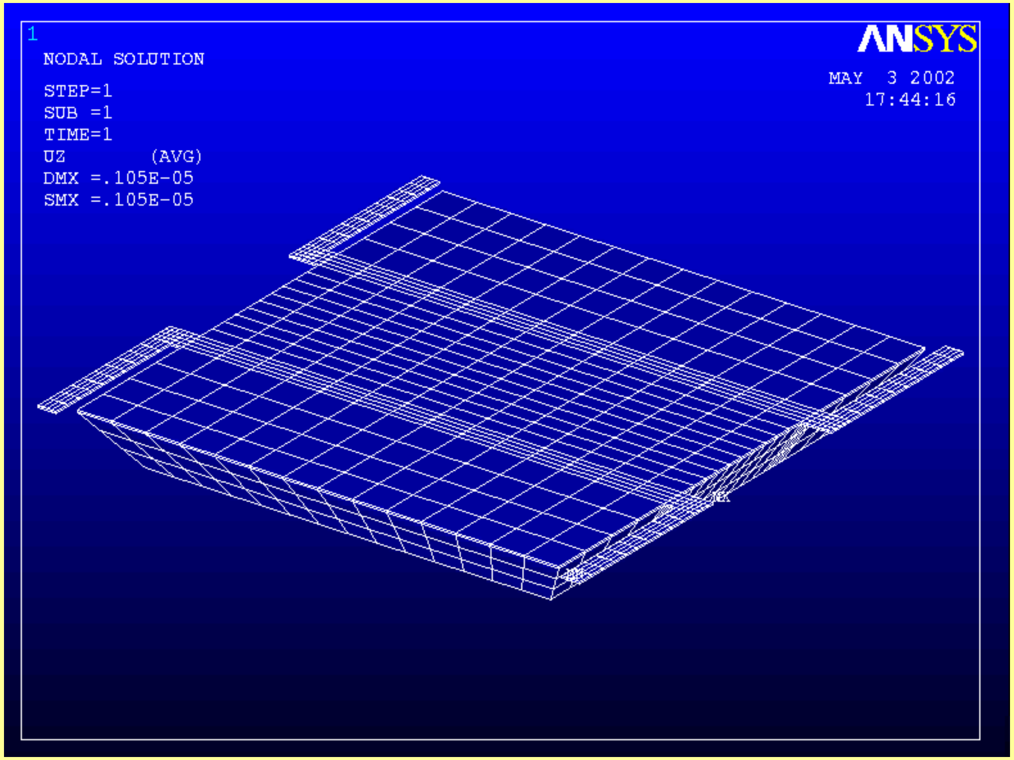
- **Idea**



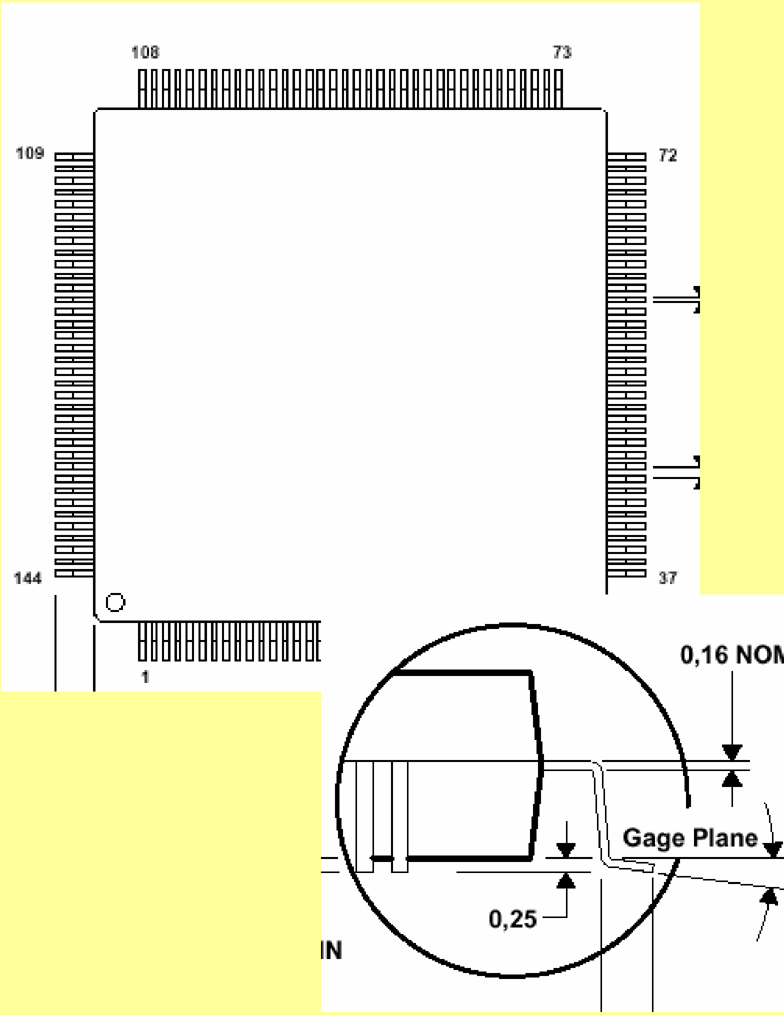
- **Design**

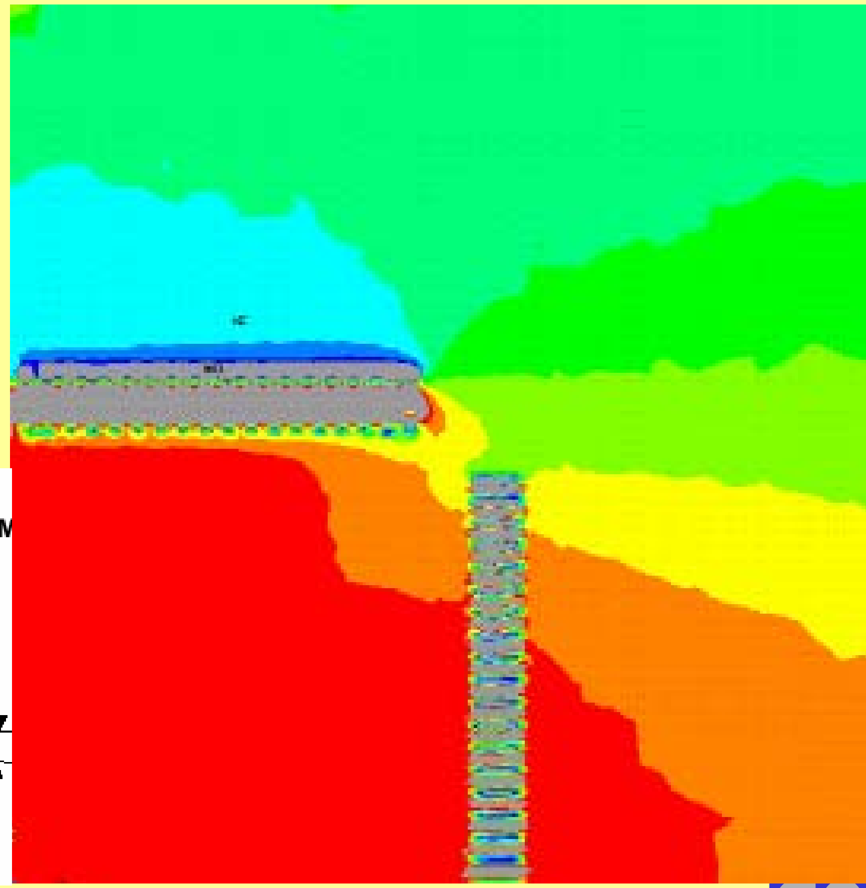
- **Simulation**





Package Thermal Strain Reduction





Images courtesy of Allen Miller, Nortel Networks

Radiation behavior
GEANT4

What is GEANT

- **A Monte Carlo software toolkit to simulate the passage of particles through matter.**
- **It is for detector simulation of research in**
  - + High energy physics
  - + Nuclear physics
  - + Cosmic ray physics
- **It is also for application in**
  - + Space science
  - + Radiological science
  - + Radiation background calculation
  - + etc

How GEANT works

- **General characteristics of a particle detector simulation program:**
  - We specify the geometry of a detector.
  - Then the program automatically transports the particle injected to the detector by simulating the particle interactions in matter based on the Monte Carlo method.
- **The heart of the simulation**
  - The Monte Carlo method to simulate the particle interactions in matter