Introduction of TCAD
(Technology Computer-Aided Design)

Physical modeling: definitions

Physical Modeling

Representation of the physical behavior of a system (device) by an abstract mathematical model which approximates this behavior. Such a model may either be a closed-form expression (analytical model), or, in general, a system of coupled (differential) equations to be solved numerically.

Analytical Modeling vs. Numerical Modeling

Analytical modeling basically means the representation of a physical property or law in terms of approximate closed-form expressions using “lumped” parameters. It is also called “compact” modeling.

Numerical modeling: modeling of the device behavior through the numerical solution of the differential equations describing the device physics on a given geometrical domain.

In the literature, the word “**modeling**” usually implies analytical/compact modeling, while “**simulation**” is much used for numerical modeling

Examples

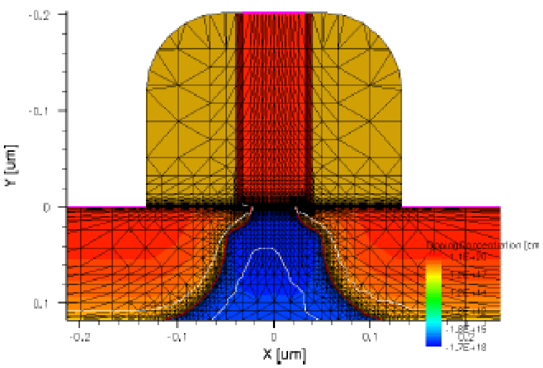
- Analytical modeling
  - I_{DS}-V_{DS} curve of a MOS transistor

$$I_D = \mu_n C_{ox} \frac{W}{L} \left[(V_{GS} - V_{TH}) V_{DS} - \frac{1}{2} V_{DS}^2 \right]$$

- Numerical modeling
  - Drift-Diffusion numerical model

$$\begin{cases} \nabla \cdot \mathscr{E} = \rho / K_S \varepsilon_0 \\ \dfrac{\partial n}{\partial t} = \dfrac{1}{q} \nabla \cdot \mathbf{J}_N - r_N + g_N \\ \dfrac{\partial p}{\partial t} = -\dfrac{1}{q} \nabla \cdot \mathbf{J}_P - r_P + g_P \\ \mathbf{J}_N = q \mu_n n \mathscr{E} + q D_N \nabla n \\ \mathbf{J}_P = q \mu_p p \mathscr{E} - q D_P \nabla p \end{cases}$$

solved at each node of a discretized domain



TCAD

Numerical simulation is much used to understand advanced device physics, for device design, scaling analyses & interaction with process manufacturing.

TCAD stands for "Technology Computer-Aided Design" is one of a numerical modelling method for semiconductor devices.

TCAD is a branch of Electronic Design Automation (EDA) that models semiconductor fabrication and semiconductor device operation. The modeling of the fabrication is termed *Process TCAD*, while the modeling of the device operation is termed *Device TCAD.* The aim of TCAD is the design of semiconductor processes and devices to fulfill some given specifications.

Process TCAD:
modeling of semiconductor-chip process-manufacturing steps like lithography, deposition, etching, ion implantation, diffusion, oxidation, silicidation, mechanical stress, etc.

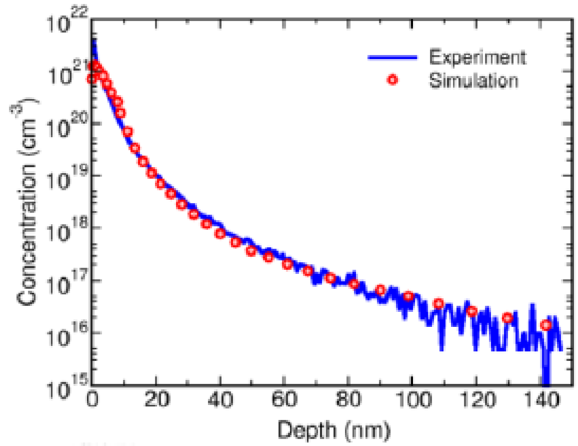
It requires detailed modeling of the *physical principles of manufacturing*, and usually also the modeling of the *specific equipments* used. Calibration of models needs expensive experiments (ad-hoc wafer fabrication, physical-chemical investigations).

Device TCAD:
modeling of electrical, thermal, optical and mechanical behavior of semiconductor devices (e.g., diode, BJT, MOSFET, solar cell,…).
It focuses on the physical principles at the basis of *carrier transport* and of *optical generation* in semiconductor devices. Models are more easily generalized than for process physics. In addition, they do not need moving boundaries/moving meshes, as instead process simulations need, i.e. convergence is in general easier. Calibration of models usually needs only electrical characterization of fabricated samples.

What is TCAD? – Examples

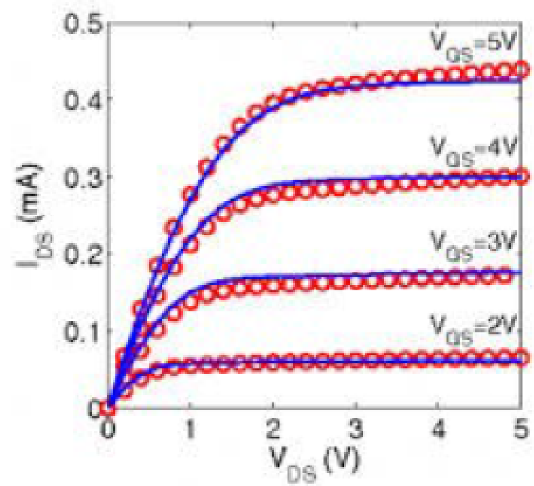
- Process simulations

  Simulate doping profiles obtained by specific processing techniques, calibrate the model with experimental data and then optimize the process to obtain the desired profile.



- Device simulations

  Simulate the output characteristics of a MOSFET device and calibrate the device architecture to fine-tune the device performance.



Advantageous of TCAD

- The device features can be optimized if hands-on calculations are too complicated or impose unacceptable assumptions
- It helps to make predictions (scaling, new device concepts) when hands-on calculations are not viable (e.g., complex devices, modeling of distributed statistical effects or process yield).
- To get insights. No real experiment will probably be ever able to measure some of the physical quantities calculated by TCAD tools (e.g., local distribution of carriers, local electric field, etc.).
- To quickly screen technological options and drive the industrial strategy