Introduction to TCAD for electronic devices

Microelectronics devices, sensors and MEMS

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Outline

- Why T-CAD simulations ?
- Overview of the simulation approach
- Device simulations
- Physical models
- Numerical solution

Why T-CAD simulations ?

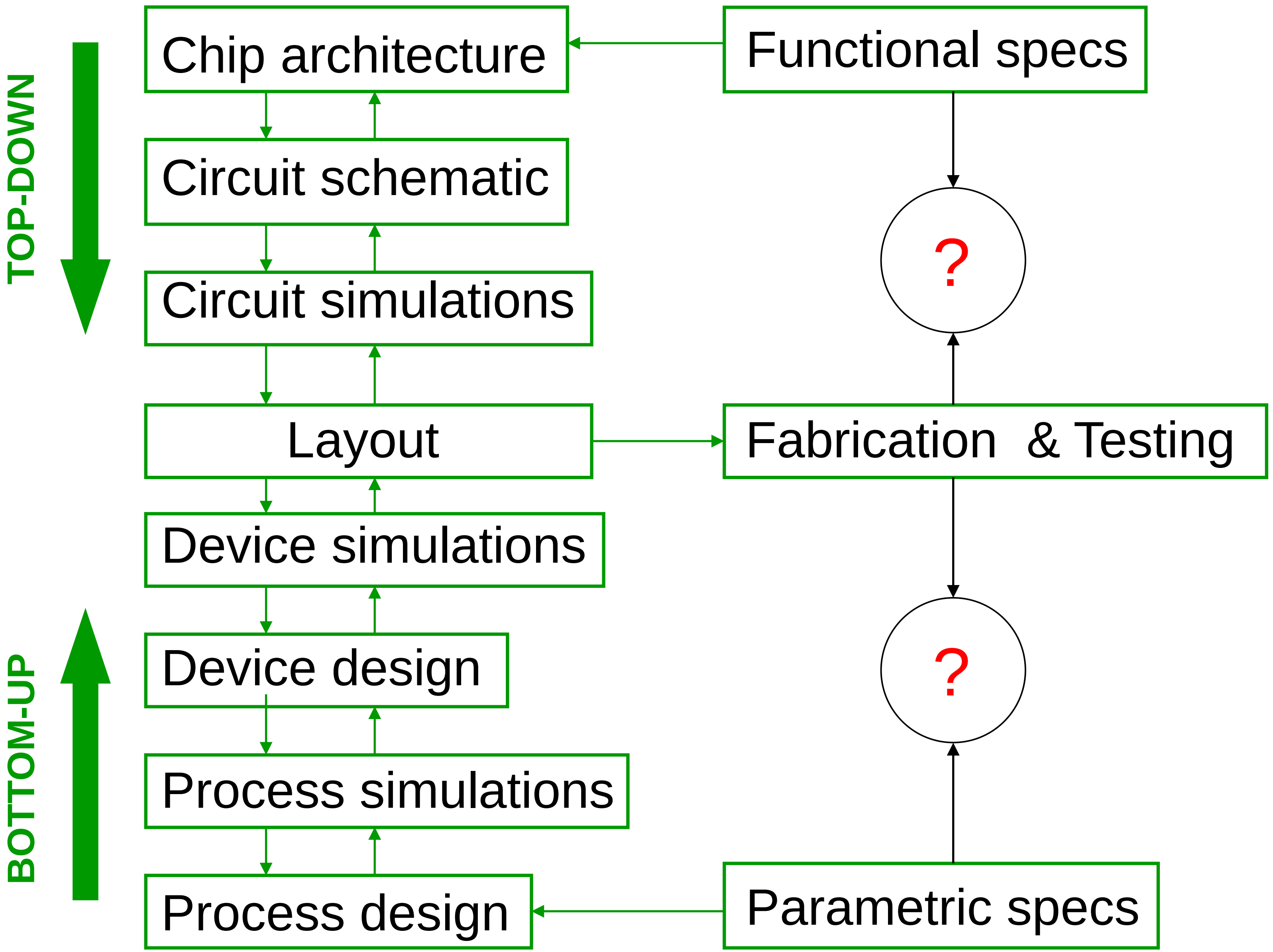
- Insight into the physical device behaviour
- Relationship between device performance and geometrical/technological parameters
- Optimize the fabrication process, while limiting the number of expensive and time consuming production cycles.

Before starting …

- Numerical simulations are powerful but should be used with care!
- The problem should be qualitatively-quantitatively studied before making simulations, in order to:

  - define a suitable grid
  - understand the results
  - address possible simulation problems
- The simulator has to be properly tuned comparing its output data to experimental results.

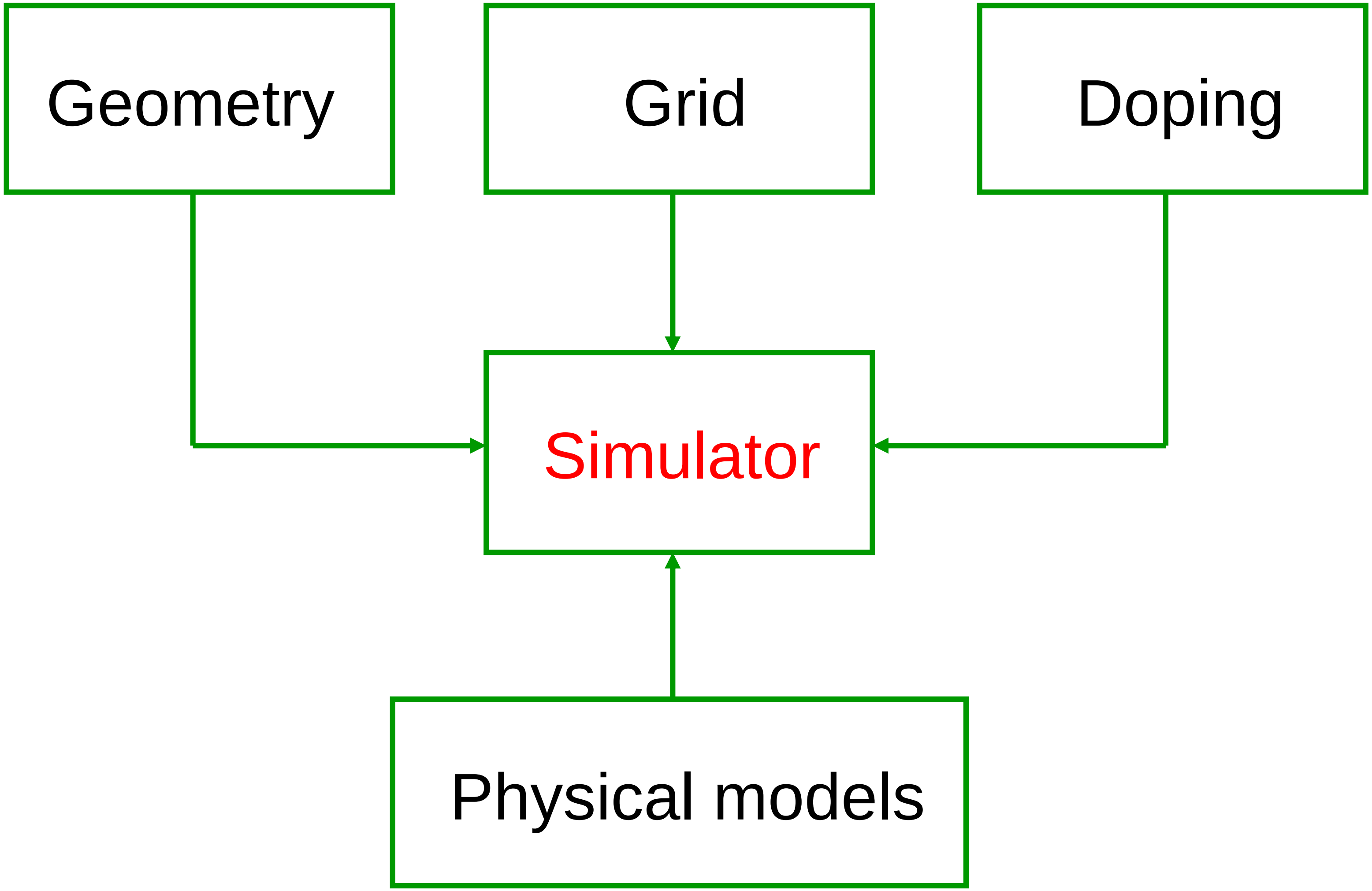
Simulation approach



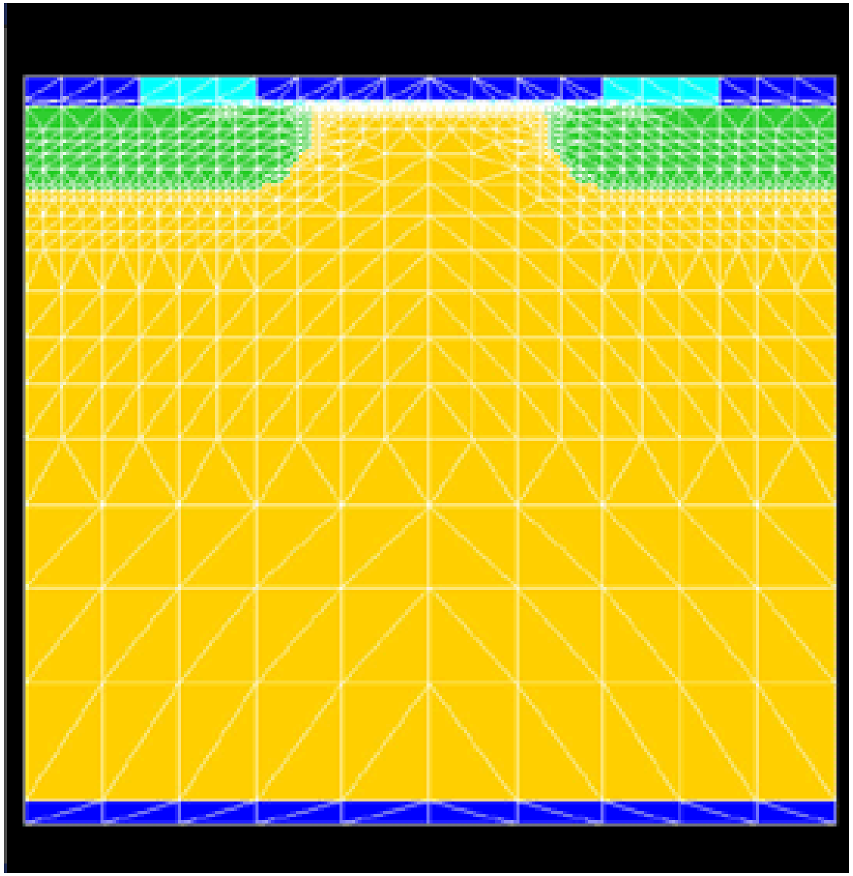
Device simulations (1)

- A device simulator solves the transport equations in a given domain under certain boundary conditions.
- The simulation domain has to be discretized, on the basis of user defined rules
- Steady-state, transient and ac analysis capabilities are included
- Many non purely electrical features like optical generation, heat transfer and radiation effects are available

Device simulations (2)



Geometry, doping, and grid



Physical Models (1)

- Mobility:

  - constant

  - dependent on doping, temperature, electric field, carrier concentration …

- Interfaces between semiconductor and insulators:

  - fixed charge

  - surface states

Physical Models (1)

- Generation-Recombination processes:
  - Shockley-Read-Hall (SRH) thermal processes
  - Auger
  - Optical
  - Impact ionization
  - Radiation

- …

Drift-diffusion model

$$\left.\begin{aligned}
J_n &= -q\mu_n n \cdot grad(\phi) + qD_n \cdot grad(n) \\
J_p &= -q\mu_p p \cdot grad(\phi) - qD_p \cdot grad(p)
\end{aligned}\right\} \text{DD transport}$$

$$div\left(\varepsilon_S grad(\phi)\right) = -q \cdot (p - n + N_D - N_A) \qquad \text{Poisson}$$

$$\left.\begin{aligned}
\frac{1}{q} div\left(J_n\right) &= -(G - R) \\
\frac{1}{q} div\left(J_p\right) &= (G - R)
\end{aligned}\right\} \text{Continuity}$$

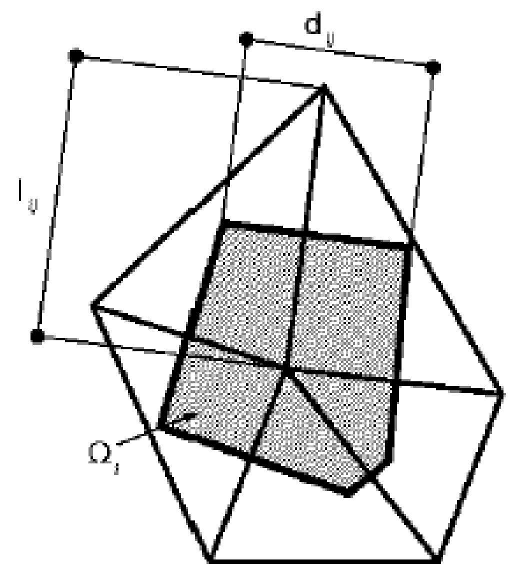
Numerical solution (1)

(N + 2) points called nodes

(N + 1) intervals called elements

Nodes and elements form the GRID

Another set of (N + 2) intervals Ω_i called cells



Numerical solution (2)

- Functions are transformed into numerical successions (nodal values of the unknowns)

- Derivatives are transformed into incremental ratios (left and right)

- The system of differential equations are transformed into a system of N algebraic equations with (N+2) unknowns (nodal values).

Discretized drift-diffusion model

$$\varepsilon_S \sum_{i\neq j}\left[\frac{d_{ij}}{s_{ij}}\left(\phi_i-\phi_j\right)\right]+q\Omega_i\cdot(n_i-p_i-N_i)=0$$

$$D_n\cdot\sum_{i\neq j}\left[\frac{d_{ij}}{s_{ij}}\left(B_{ji}n_i-B_{ij}n_j\right)\right]+\Omega_i\left(R-G\right)_i=0$$

$$D_p\cdot\sum_{i\neq j}\left[\frac{d_{ij}}{s_{ij}}\left(B_{ji}p_i-B_{ij}p_j\right)\right]+\Omega_i\left(R-G\right)_i=0$$

Where $B_{ij}=\dfrac{u_{ij}}{\exp(u_{ij})-1}$ and $u_{ij}=\phi_i-\phi_j$

Boundary conditions

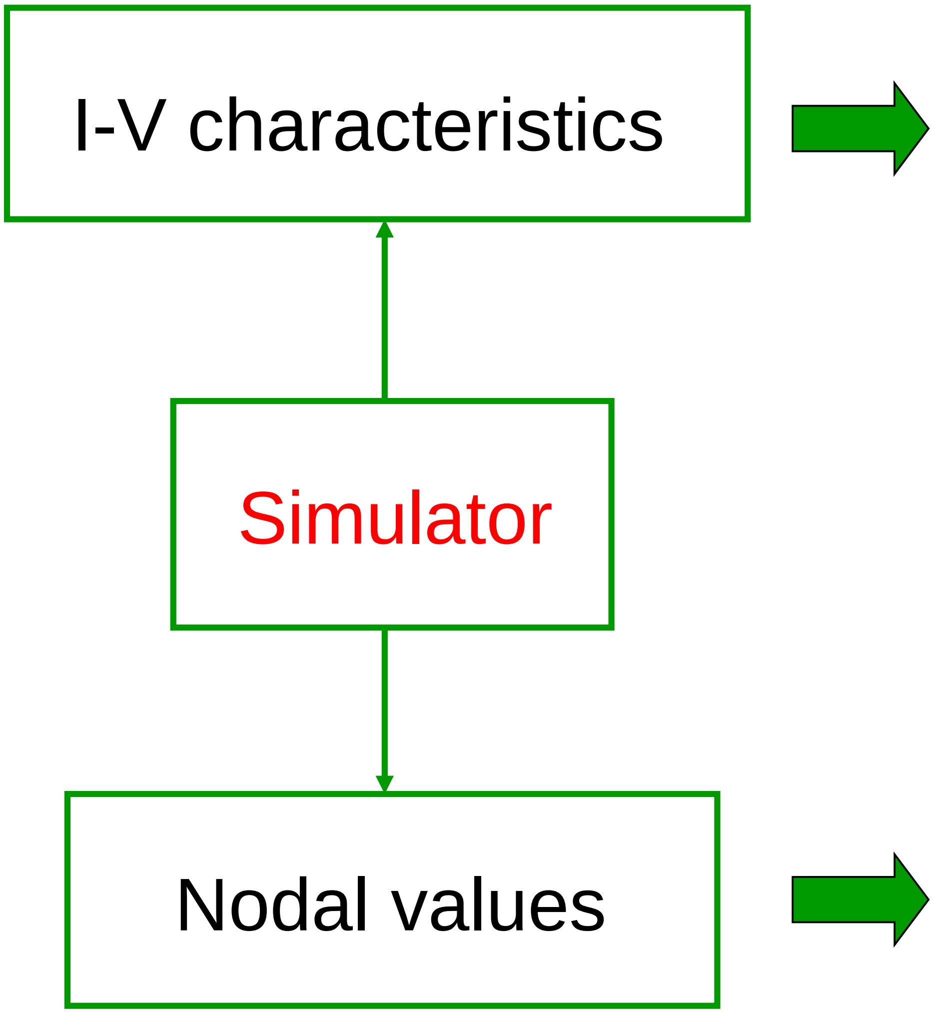
- Ohmic contacts: sets the value of the semiconductor potential at the contact surface (Dirichlet)

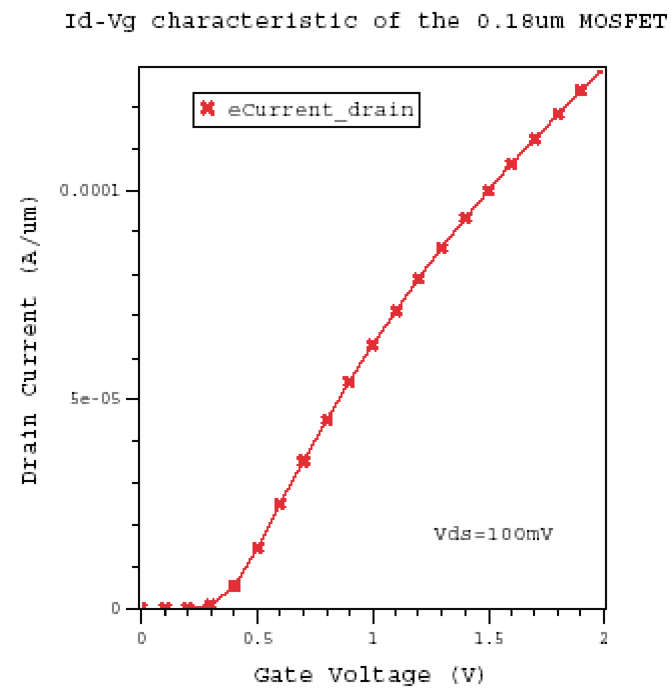
$$\phi = V_{EXT}$$

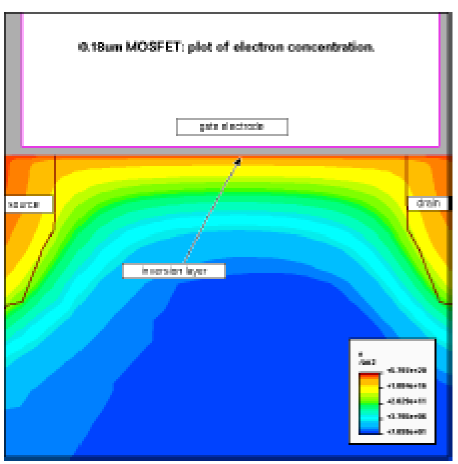
- Reflective boundary conditions (Von Neumann)

$$\begin{cases} \overrightarrow{J_n} \cdot \overrightarrow{N} = 0 \\ \overrightarrow{J_p} \cdot \overrightarrow{N} = 0 \end{cases}$$

Simulation output







Tool Flow in Synopsys TCAD

- Design the device
- Simulate the device
  - Temperature, Bias
  - Stimulus
- Analyze the simulation results
  - IV curve
  - Carrier distribution
  - Electrostatic potential
  - …