Process simulation

Front End of Line Process Models

Ion Implantation, Diffusion

Epitaxy, Oxidation,

Device simulation

Equipment simulation

Equipment Modeling, Transport Simulation

PVD (Monte Carlo, MD (*))

Feature scale, Topography (line of sight))

Lithography

CMP

CVD (*)

ECD

Etching (*)

ALD

Modeling & Simulation SCOPE & SCALES

Modeling Overall Goal

- ***Support technology development and optimization***
- ***Reduce development times and costs***

Challenges: Nano scale device modeling

Tools for the development of novel nanostructure devices

. quantum transport .spintronics .contacts

- Coupling of optical and electrical systems
- Models for optical interconnects
- Methods, models and algorithms that contribute to prediction of CMOS limits
- Gate stack models
- Models for device impact of statistical fluctuations
- Stress models
- Tools for the design of integrated electrical/optical systems
- Air gap and novel 3D integration

High-frequency device and circuit modeling up to 100 GHz applications

- Efficient extraction and simulation of full-chip interconnect delay and power consumption
- Accurate and yet efficient 3D interconnect models, especially transmission lines and S-parameters
- Extension of physical models to III/V mterials
- High-frequency circuit models including non-quasi static effects, substrate noise, and parasitic coupling
- Parameter extraction assistet by numerical electrical simulation instead of RF measuremants
- Scaleable active and passive component models for compact circuit simulation
- Co-design between interconnects and packaging

Modeling of chemical, thermomechanical, and electrical properties of new materials

- Operating behavior for new materials applied in devices and interconnects
- Gate stacks, Predictive modeling of dielectric constant
- Surface states
- Thermomechanical properties
- Optical properties
- Reliability
- Breakdown
- Leakage currents
- Tunneling

- Linkage with first principle computation and classical MD and thermodynamic computation
- ULK models

Nano scale process modeling

Process modeling tools for the development of novel nanostructure devices

CNT

nanowires (doped, decorated)
quantum dots, molecular electronics

Process models for optoelectronic devices

- Computer-efficient inclusion of influences of statistics
- Efficient extraction of circuit-level variations from process and device simulation

Front-end process modeling for nanometer structures

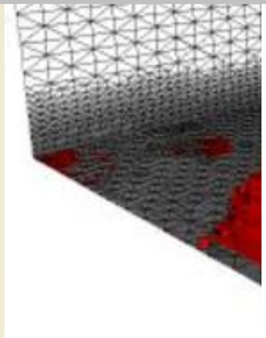
- Diffusion/activation/damage/stress models
- (Si, SiGe:C, Ge, SOI, epilayers, ultra-thin body devices
- Epi-layer modeling (stress, morphology
- Low dopant level characterisation
- Modeling hierarchy from atomistic to continuum for dopants and defects in bulk and at interfaces
- Front-end processing inpact on reliability

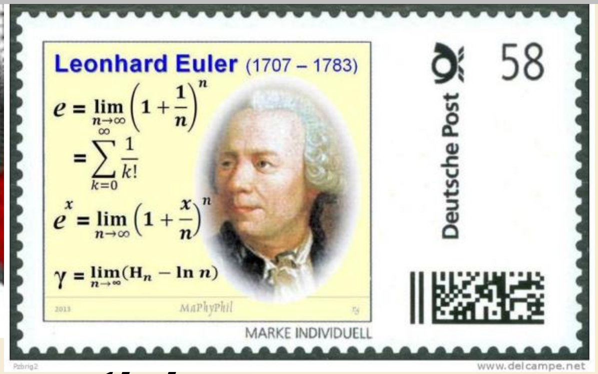
Integrated modeling of equipment, materials, feature scale processes and influence on devices

- Fundamental physical data: rate constants, cross sectons
- Simplified but physical models for complex chemistry and plasma reaction
- Linked equipment/feature scale models
- CMP, etch, electrochemical polishing ECP, pattern dependent effects
- MOCVD, PECVD, ALD, EP, ELD modeling

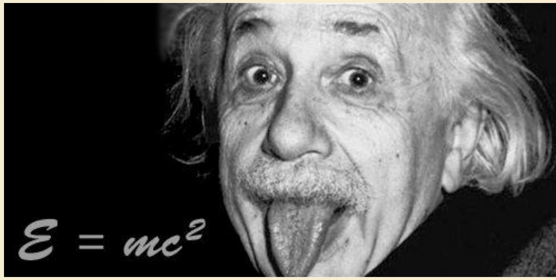
… to find the right parameters

1. Parameter of Numerical Method,
   (e.g. discretisation in space and time)
2. Parameter of the Physial Model
3. Parameter of the Equipment (Dim...)
4. Parameter of the Process (T, flow..)





mathematician



physicist

engineer

economist

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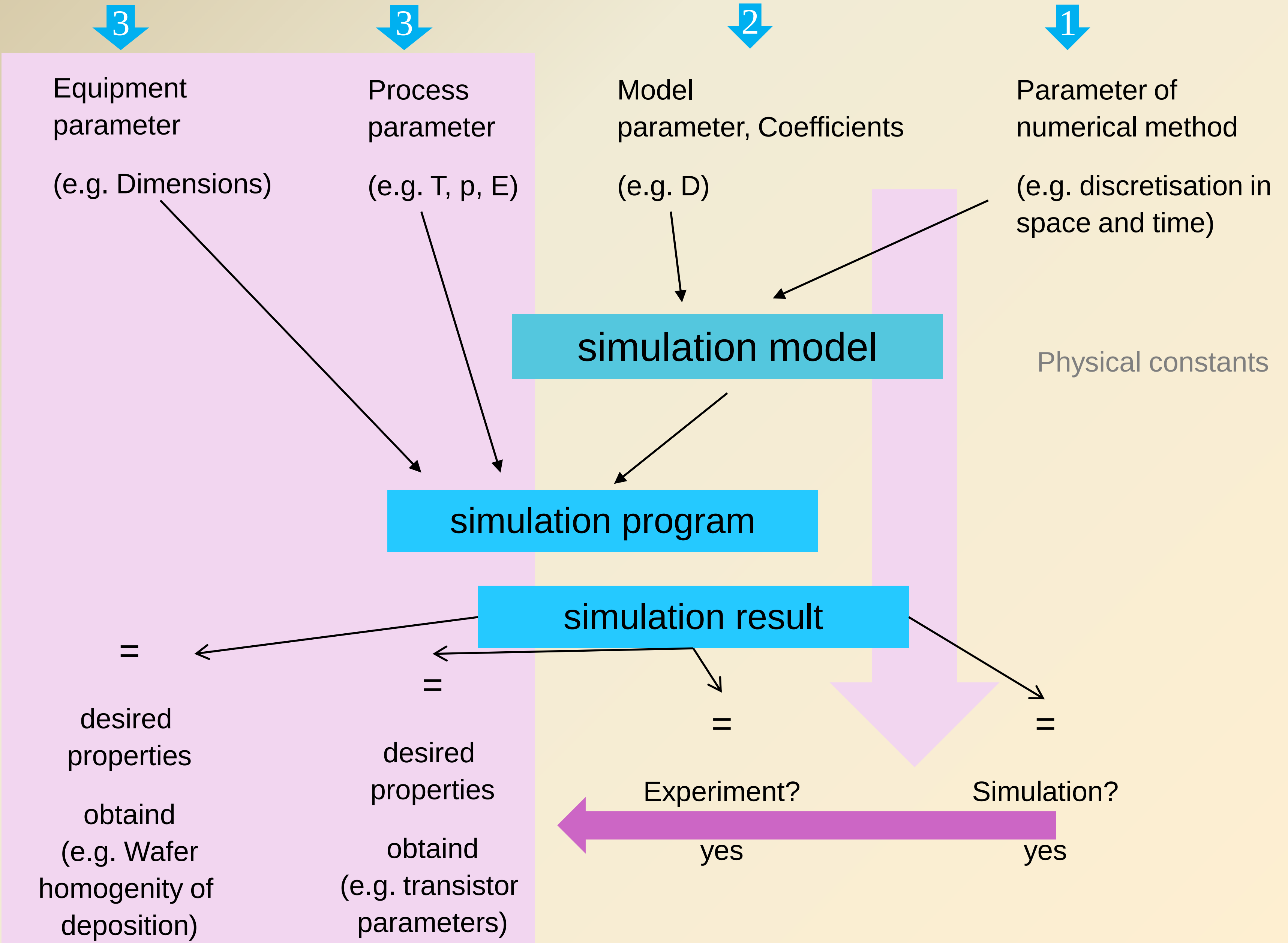
Overall goal of simulation: optimization of parameters



Simulation of Thin Film Deposition

Outline

- General Remarks: Properties and Applications of Thin Films
- Small Structures, an Example, The ITRS and one Physical Limit: The Size Effect
- Simulation Models depending on Pressure and Dimensions
- CVD Modeling and Simulation
- ECD
- ALD
- PVD Modeling and Simulation
- Summery

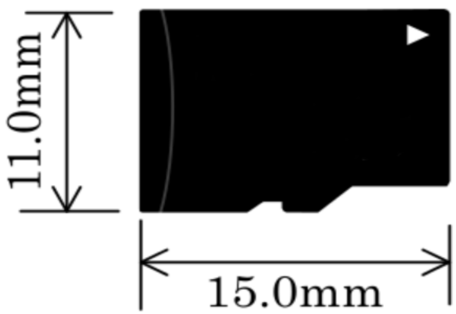
- A **thin film** is a layer of material ranging from fractions of a nanometer (monolayer) to several micrometers in thickness (1 µm!)
- special physical properties like interference, useful for sensitive layers in sensors
- expensive materials can be used economically
  - hard coatings
  - anticorrosion layers
- **microelectronics**
  - CDs/DVDs, hard disks
  - electronic semiconductor devices / IC (processors, memory..)
  - optical devices (LEDs)
  - energy generation (thin film solar cells) and storage (thin-film batteries)
  - multiferroic materials / superlattices that allow the study of quantum confinement by creating two-dimensional electron states.

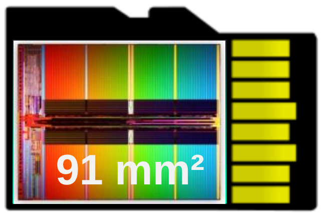
optical coatings

Source: WiKi

Density of µElectronic Structures, Example

SanDisk
200 GByte Micro-SD
0,7 mm thick
16 stacked flash dies
1 controller die





91 mm² die size (estimated)

Total die area (incl. bus system...)
= 16 * 91 mm²
= 1456 mm²

Space for
200 000 000 000 * 8 memory cells

per memory cell an area of

A_{cell} = 1456 mm² / 1.6e12 (Terabit)

A_{cell} = **910 nm²**

A_{hair}/ A_{cell} = 3848 µm²/910 nm²

A_{hair}/ A_{cell} > 4 000 000

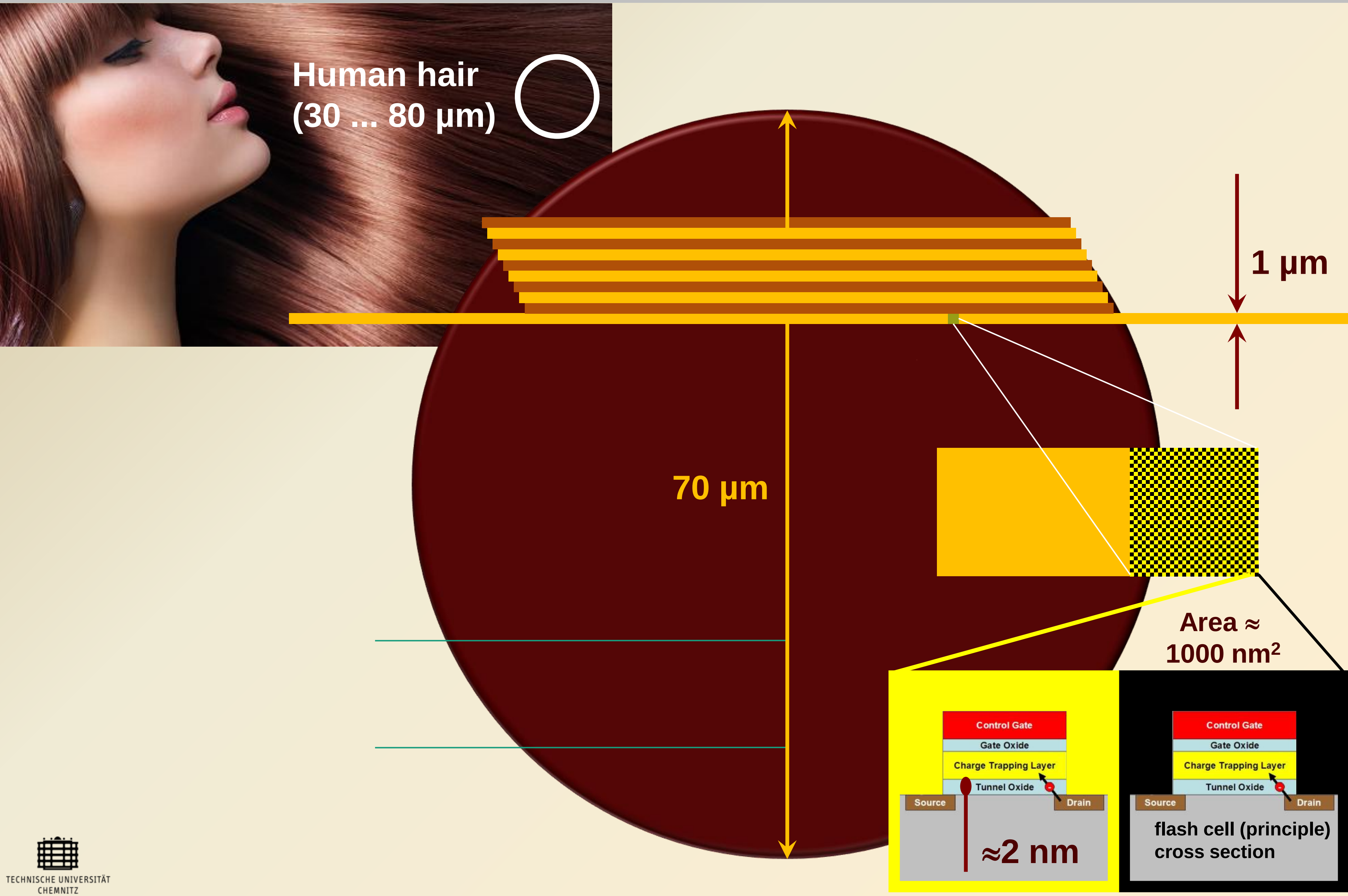
Human hair diameter d =70 µm

Cross section area

$A_{hair} = \pi/4\ d^2 =$ **3848 µm²**

May 2016
Samsung
256 GByte Micro-SD

Density of µElectronic Structures, Example



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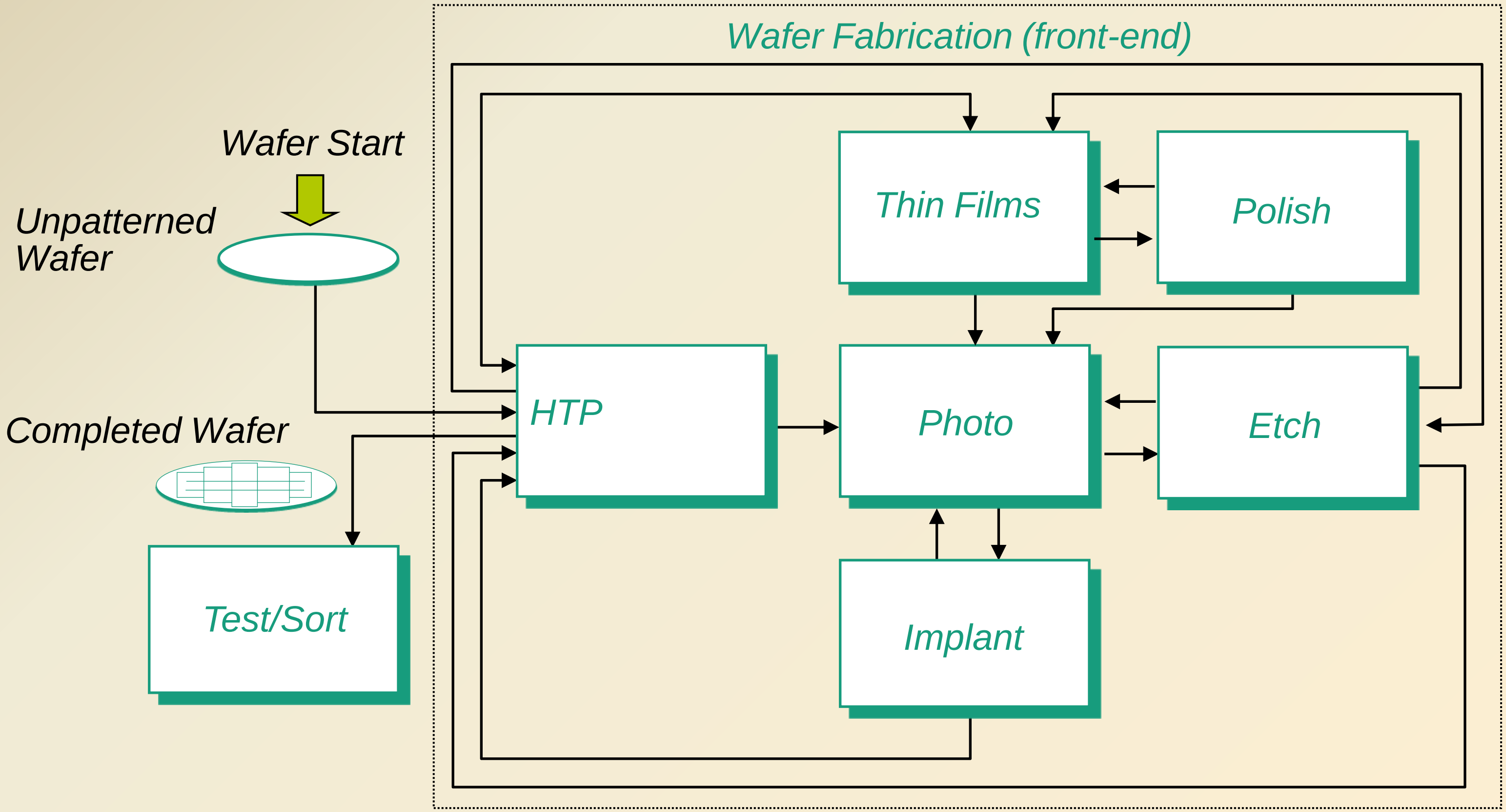
Model of Typical Wafer Flow in a Sub-Micron CMOS IC Fab



6 major production areas

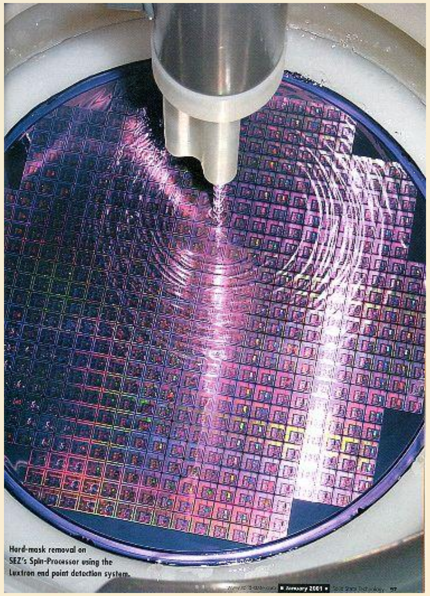
HTP:

High Temperature Processes: Diffusion, Oxidation, Anneal, Epi

6 ... 8 weeks involve up to 400 process steps

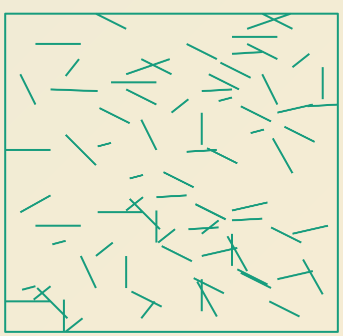
- Cleaning
- Etching
- Packaging
- Waferbonding
- **Thin Film Deposition**
- Lithography
- Doping
- Cleaning
- Measuring Technique

CVD Chemical Vapour Deposition / Epitaxy
ALD Atomic Layer Deposition
PVD Physical Vapour Deposition(Sputtering/Evaporation)
ECD Electro Chemical Deposition
MBE Molecular beam epitaxy
spin on



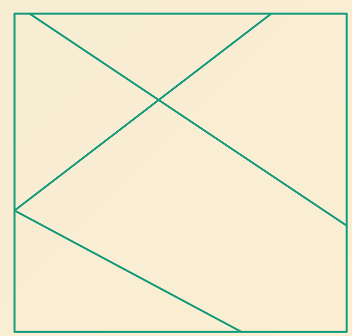
Transport Simulation depending on Pressure (mfp) and Dimensions, Knudsen number

- The **Knudsen number** (**Kn**) is a dimensionless number defined as the ratio of the molecular **mean free path** length to a **representative physical length scale**. This length scale could be, for example, the radius of a layer deposition reactor.
- The Knudsen number helps determine whether **statistical mechanics** or the **continuum mechanics** formulation of **fluid dynamics** should be used to model a situation.
- If the Knudsen number is near or **greater than one**, the mean free path of a molecule is comparable to a length scale of the problem, and the **continuum assumption** of fluid mechanics is no longer a good approximation. In such cases, **statistical methods** should be used.



Kn < 1

transport is determined by particle - particle interaction



Kn > 1

transport is determined by particle - wall interaction

$$Kn = \frac{\lambda}{L}$$

- λ = mean free path [L^1],
- L = representative physical length scale [L^1].

For a Boltzmann gas, the mean free path may be readily calculated, so that

$$Kn = \frac{k_B T}{\sqrt{2}\pi d^2 p L}$$

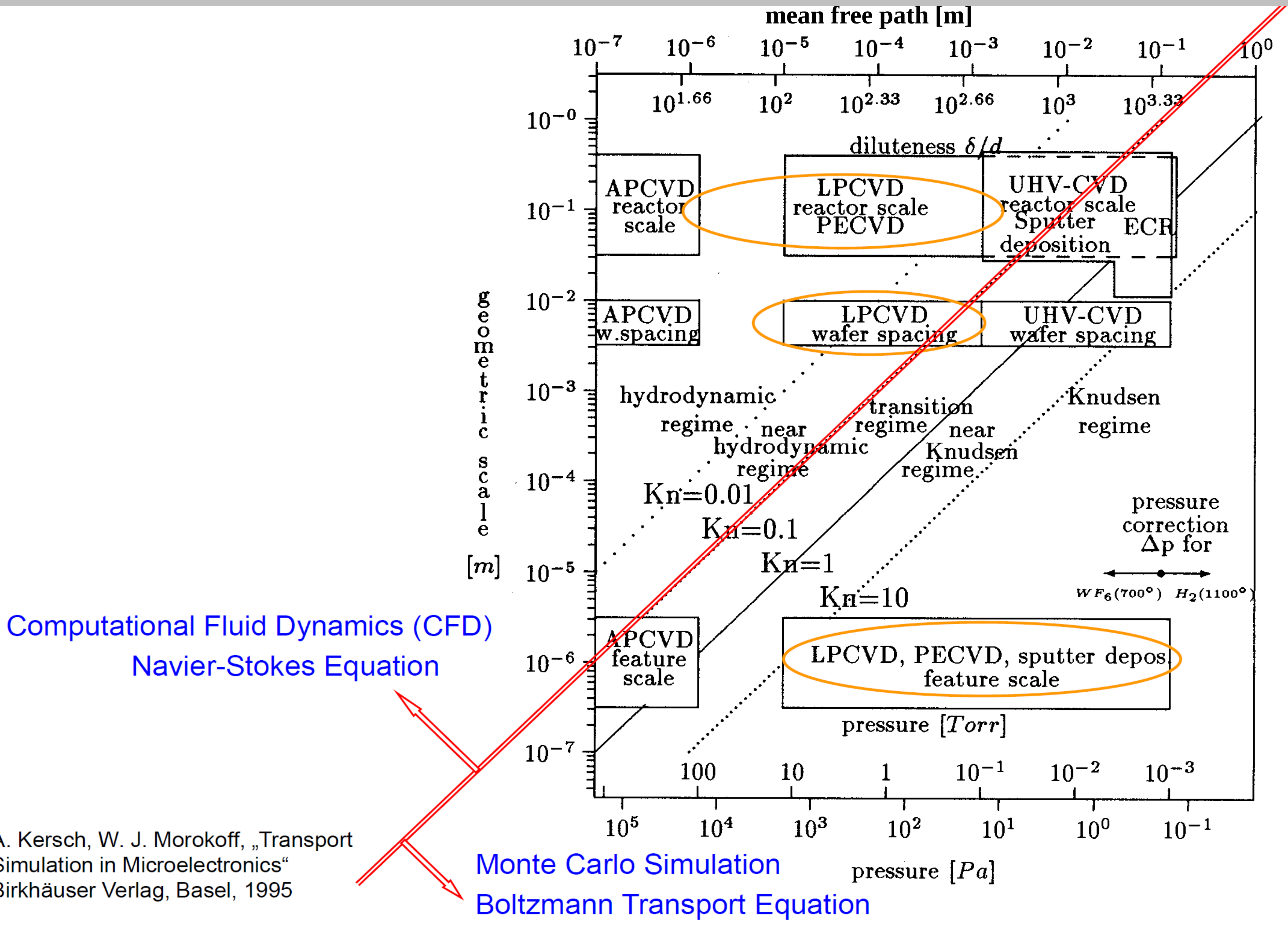
- k_B is the Boltzmann constant (1.3806504(24) × 10^{-23} J/K in SI units), [M^1 L^2 T^{-2} θ^{-1}],
- T is the thermodynamic temperature, [θ^1],
- d is the particle hard-shell diameter, [L^1],
- p is the total pressure, [M^1 L^{-1} T^{-2}].

For particle dynamics in the atmosphere, and assuming standard temperature and pressure, i.e. 25 °C and 1 atm, we have $\lambda \approx 8 \times 10^{-8}$ m (80 nm).

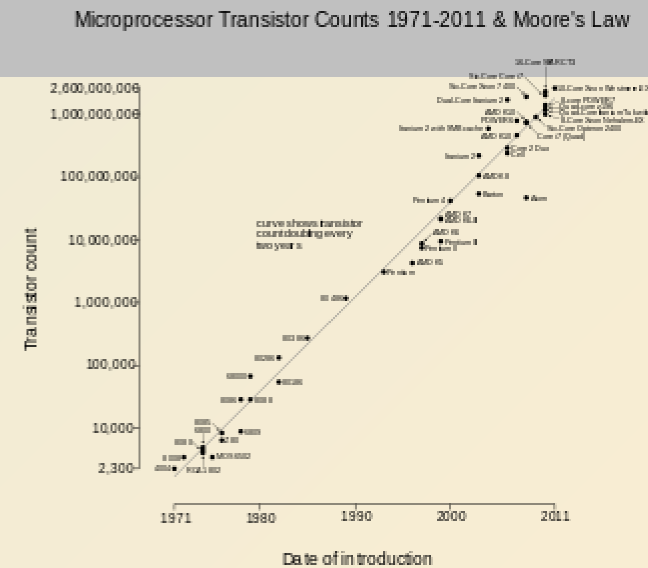
Mean Free Path vs. Pressure

Vacuum range	Pressure / hPa	Atoms / cm^3 Molecules / cm^3	Aver. Dist. Between atoms / molecules	Mean free path
(reference: Silicon, typical doping concentration in Silicon)	-	$5 \cdot 10^{22}$ 10^{15} ... 10^{20}	**L = 0.235 nm (**bond length)**,** L=¼ √3a a = 0.543 nm (lattice constant)	-
Ambient pressure	1013	$2.7 \cdot 10^{19}$	≈3.3 nm	68 nm
Low vacuum	300 ... 1	10^{19} ... 10^{16}	≈ 5 nm ... 50 nm	0.1 ... 100 µm
Medium vacuum	1 ... 10^{-3}	10^{16} ... 10^{13}	≈ 50 nm ... 0.5 mm	0.1 ... 100 mm
High vacuum	10^{-3} ... 10^{-7}	10^{13} ... 10^{9}	≈ 0.5 mm ... 10 µm	10 cm ... 1 km
Ultra high vacuum	10^{-7} ... 10^{-12}	10^{9} ... 10^{4}	≈ 10 µm... 0.500 mm	1 km ... 10^{5} km
Extremely high vacuum	< 10^{-12}	< 10^{4}	≈ < 0.500 mm	> 10^{5} km

Tansport Simulation in Relation to geometric Scale



A. Kersch, W. J. Morokoff, „Transport Simulation in Microelectronics“ Birkhäuser Verlag, Basel, 1995



July 28, 2016 HPCwire

Transistors Won't Shrink Beyond 2021, Says Final ITRS Report

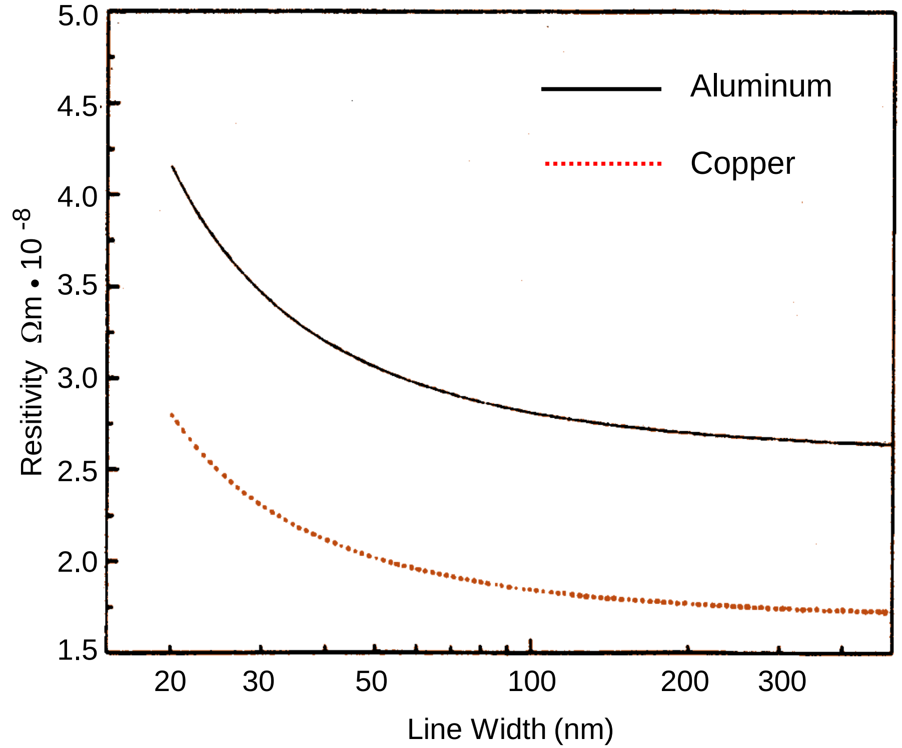
Tiffany Trader

The final International Technology Roadmap for Semiconductors (ITRS) is now out.
ITRS: The highly-detailed multi-part report, collaboratively published by a group of international semiconductor experts, offers guidance on the technological challenges and opportunities for the semiconductor industry through 2030.
One of the major takeaways is the insistence that Moore's law will continue for some time even though traditional transistor scaling (through smaller feature sizes) is expected to hit an economic wall in 2021.

Moore's law is the observation that the number of transistors in a dense integrated circuit doubles approximately every two years. (1965)

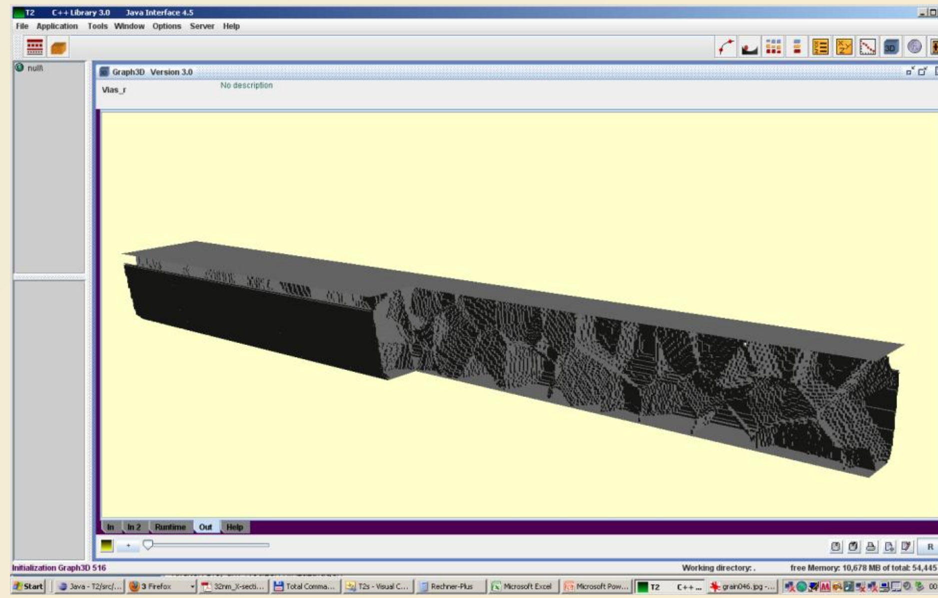
Gordon Moore: co-founder of Intel and Fairchild Semiconductor

F. Chen, D. Gardner, IEEE Electron Dev. Lett. **19**, 508 (1998)



Tech node	Interconnect pitch	Interconnect width (incl. barrier)
10 nm	34	17
7 nm	22	11

Interconnect Models



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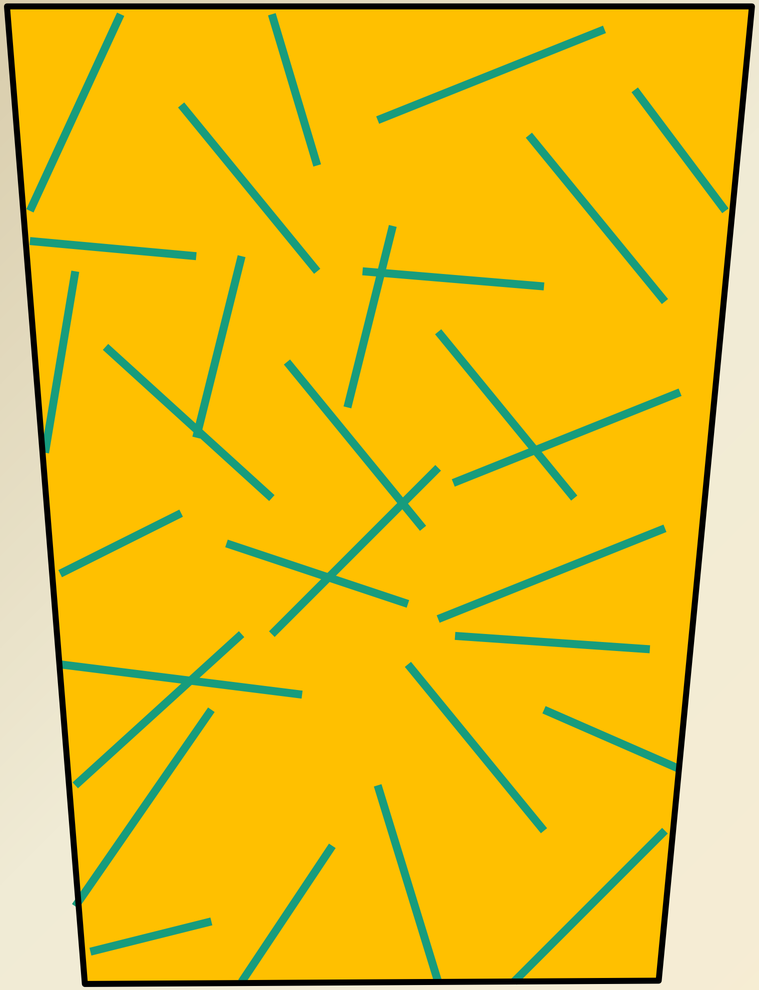


elementary charge

Number of electrons with Fermi-energy

relaxation time

$$\sigma = \frac{N_f e^2 \tau}{m_{eff}}$$

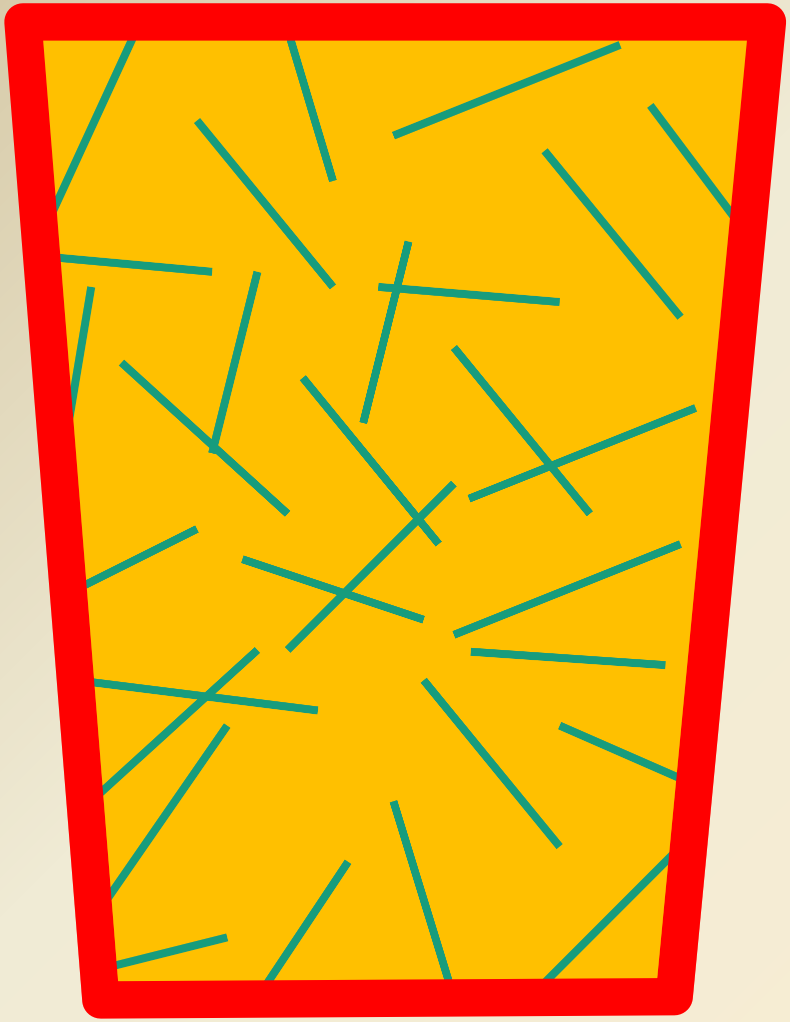
effective mass of electrons

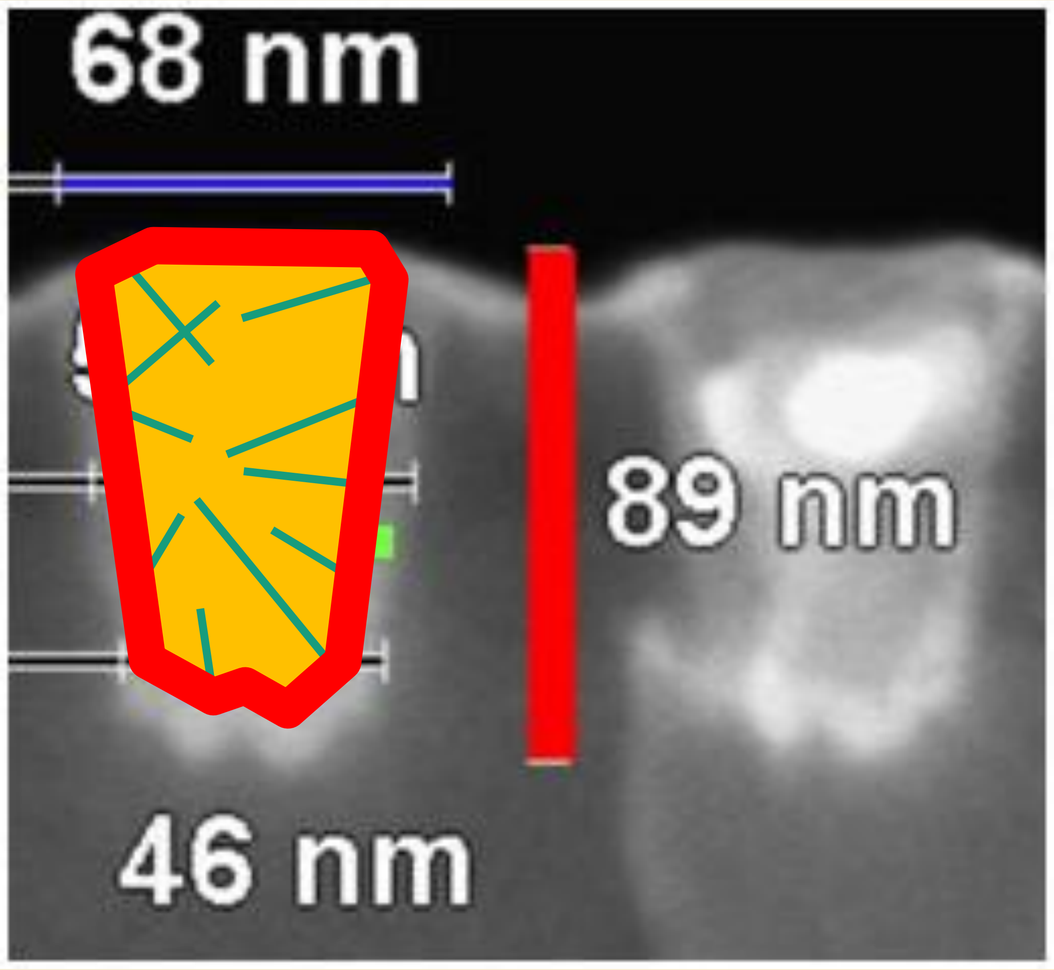
relaxation time ..mean free path of electrons (Copper 39 nm)

resistivity = 1.6 µOhm cm

The Size Effect

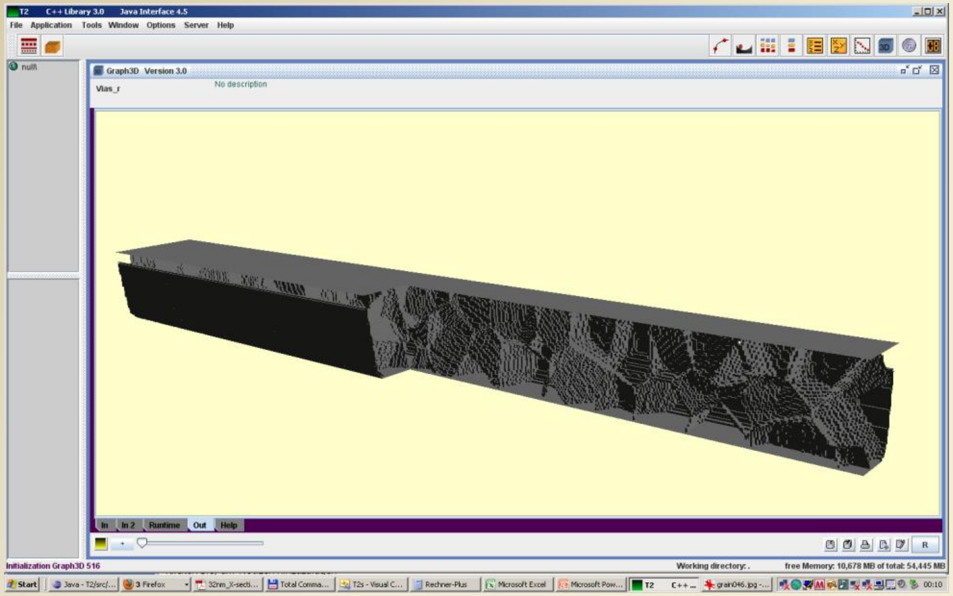
copper interconnects





To inhibit the detrimental **diffusion of copper into silicon devices**, an effective barrier is strongly demanded.

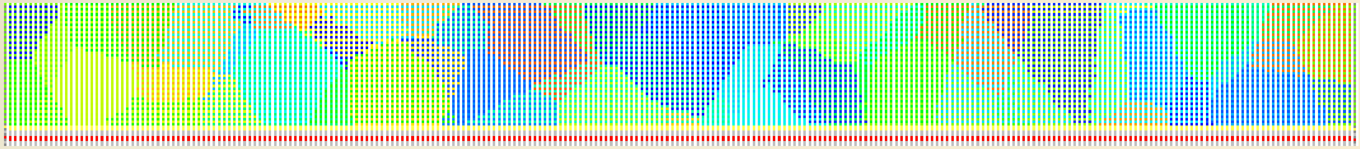
The Size Effect: Structure Generation with Simulator T2 for Size Effect Simulation



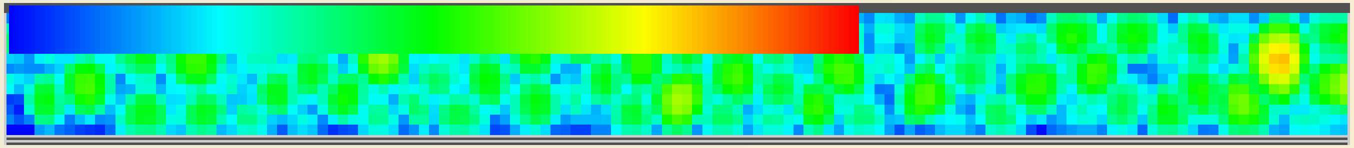
Grain structure, randomly generated

Lattice resolution = 1nm

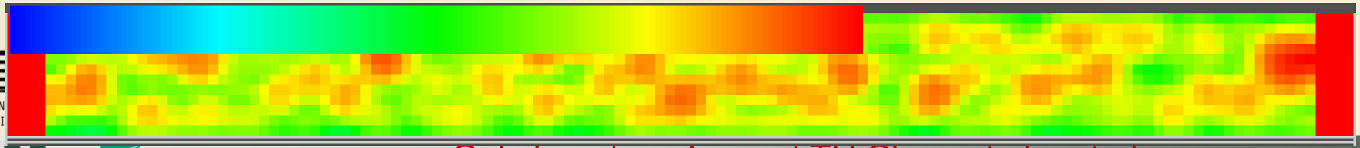
τ (x,y,z) σ(x,y,z) Poisson eq.



Grain Structure



Local relaxation time

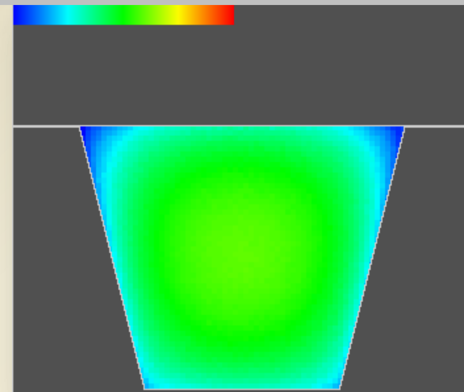


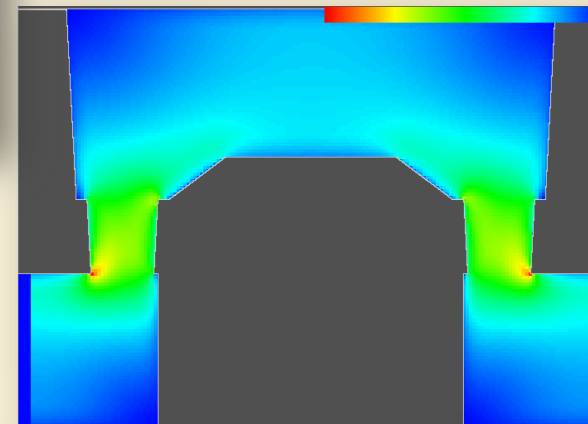
Current density

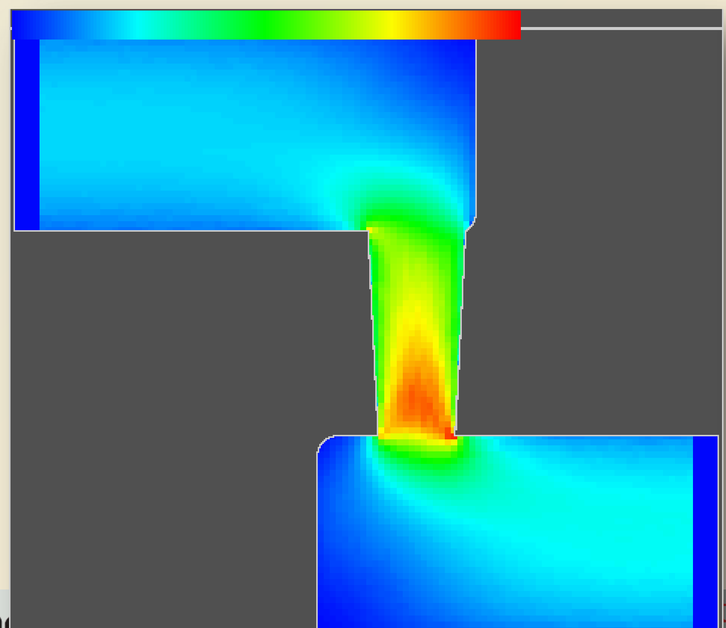
The Size Effect: Simulation Results

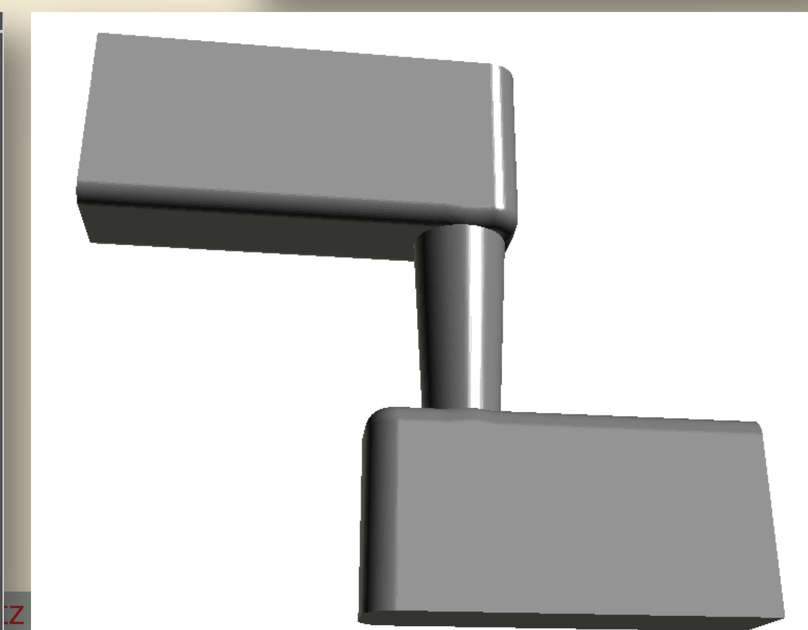
Technology optimization improves conductivity (grain structure and surface quality, e-reflection).

Simulation can help to understand the transport in complex structures.



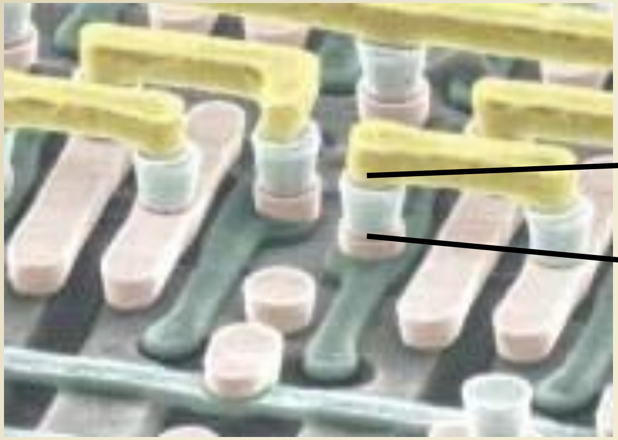


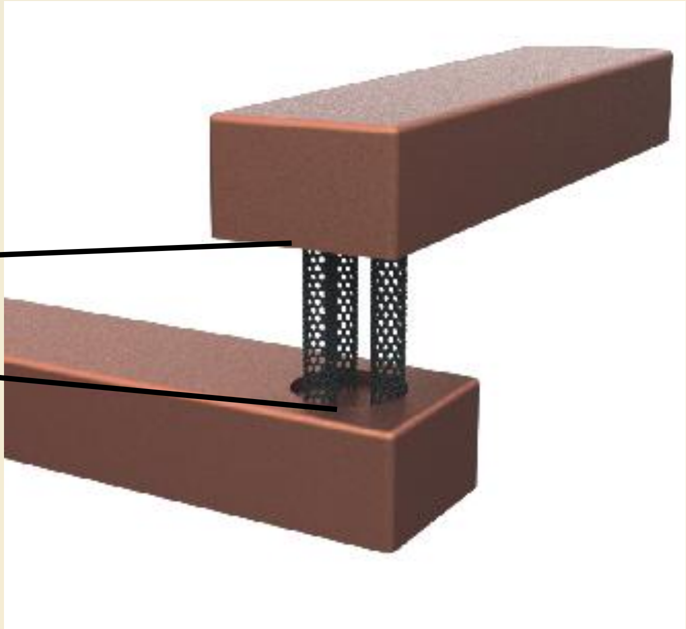




Solution: Replacement of metal interconnects with Carbon Nanotubes ?

- ✓ No electromigration issues
- ✓ High current carrying capacity
- ✓ Thermal management





CNT-Via/Metal-Hybridstructure

CVD Chemical Vapour Deposition / Epitaxy

ALD Atomic Layer Deposition

PVD Physical Vapour Deposition

ECD Electro Chemical Deposition

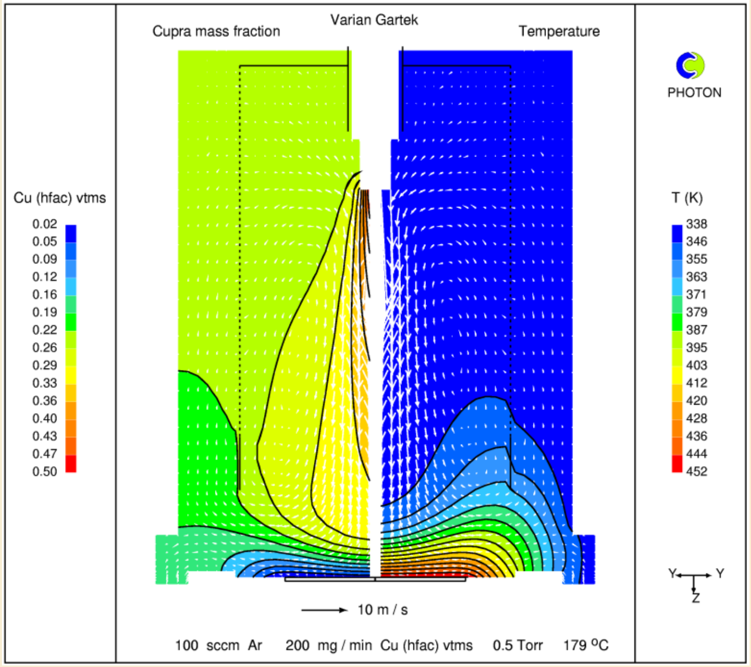
MBE Molecular beam epitaxy

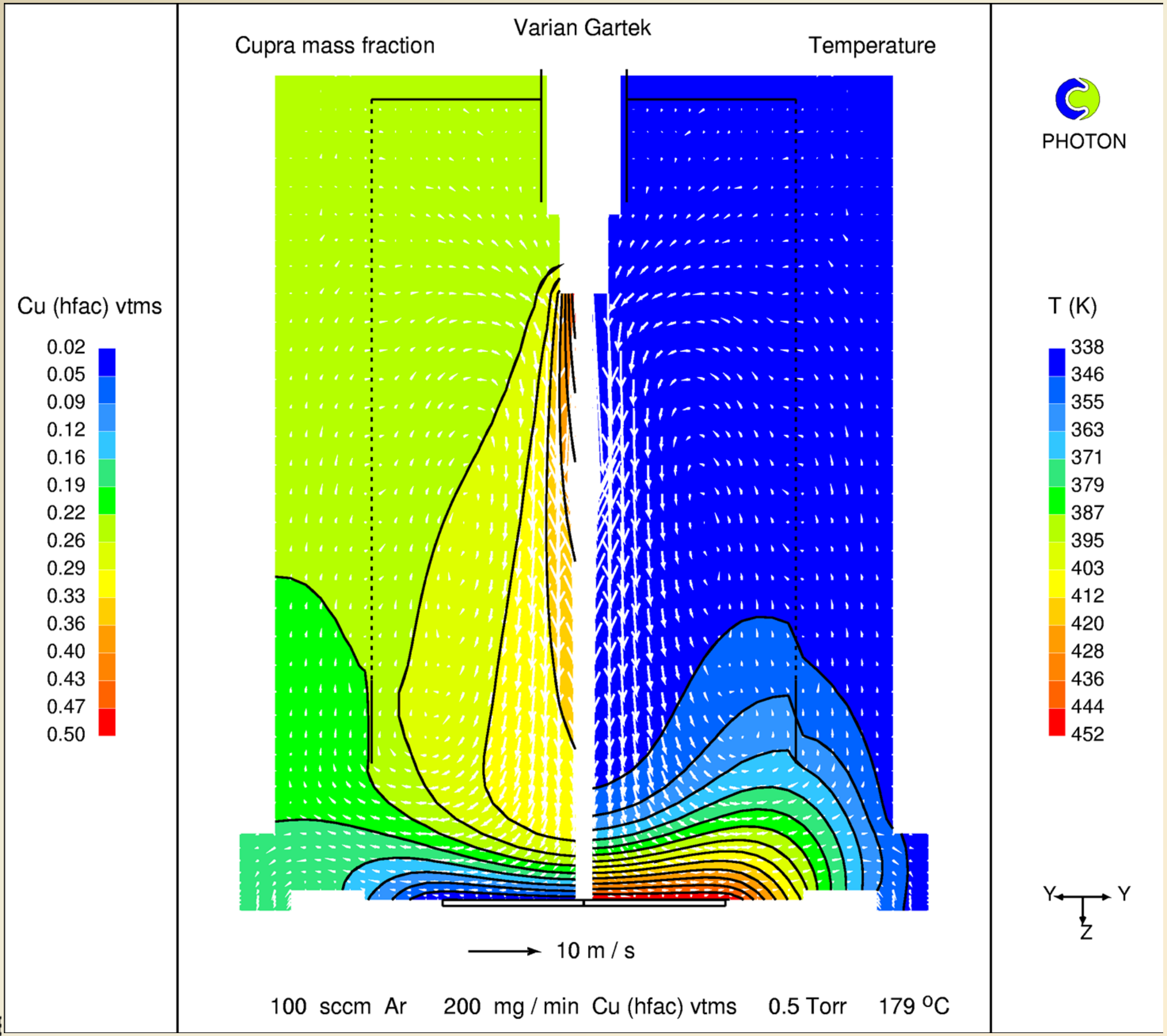
spin on

...Modeling and Simulation

Transport Simulation

1. Particles to wafer





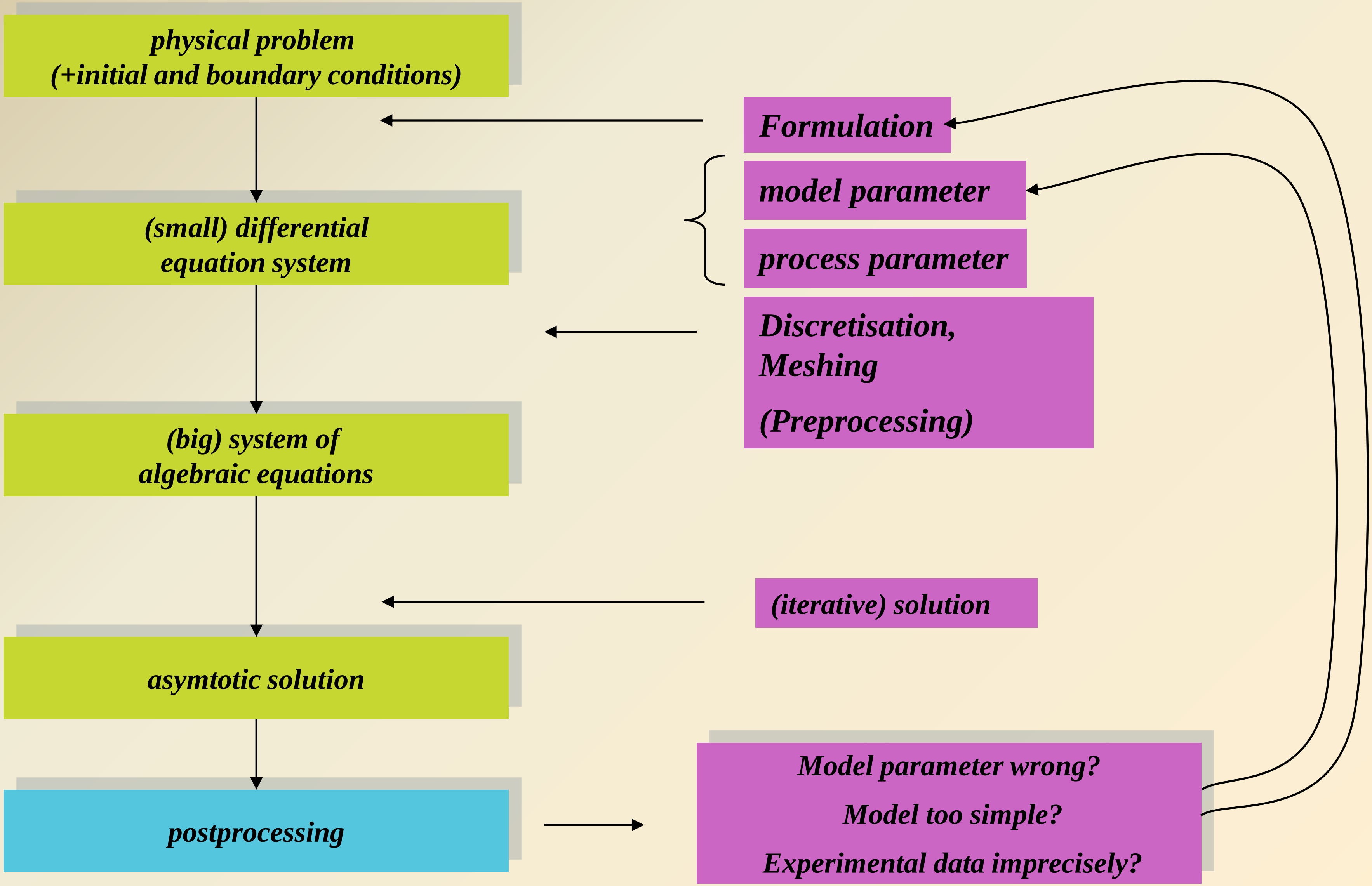
Improvement of

- deposition rates
- uniformity
- fill behavior of vias and trenches

by **optimization** of

- process conditions
- reactor configuration

Mathematical methods



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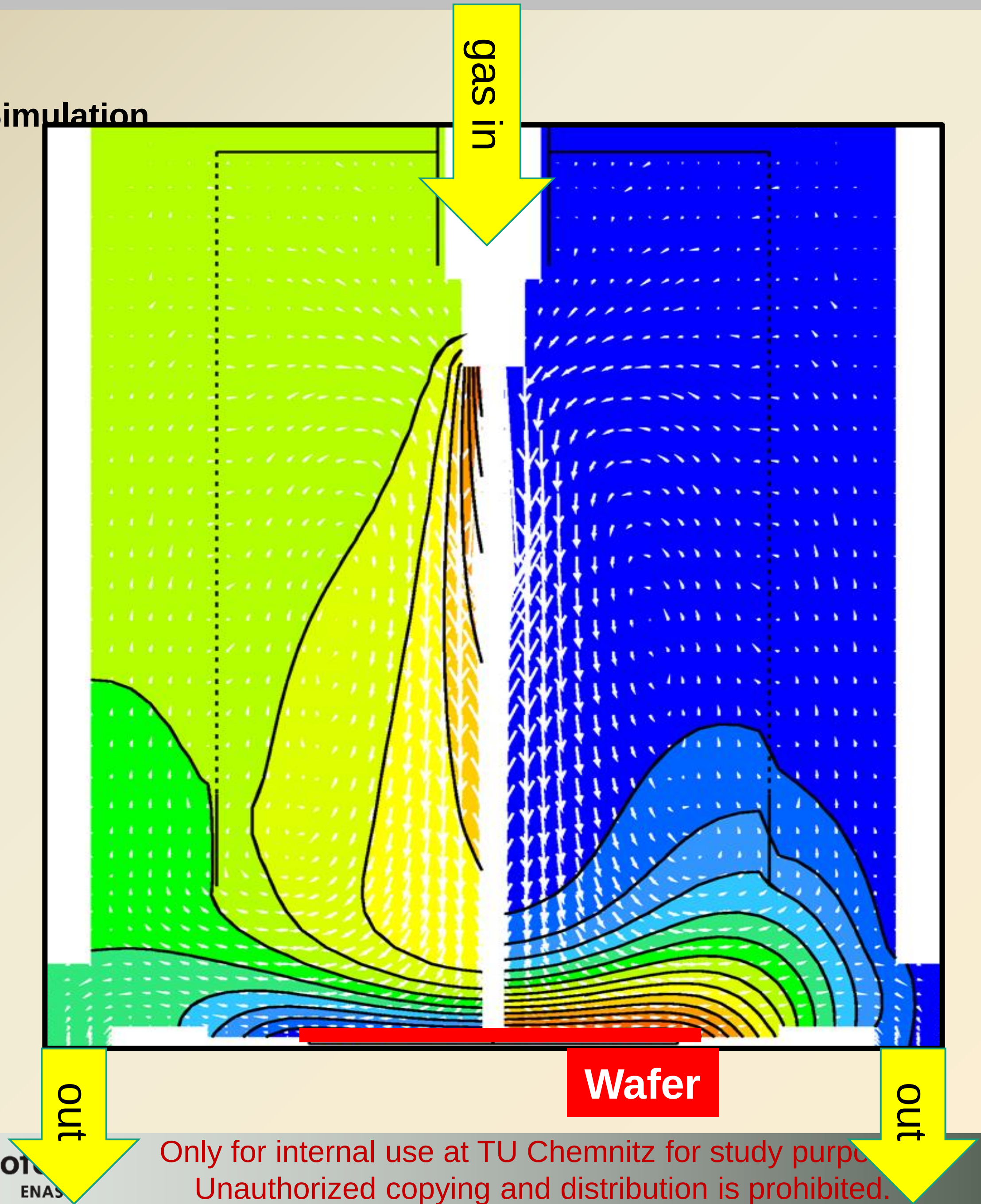
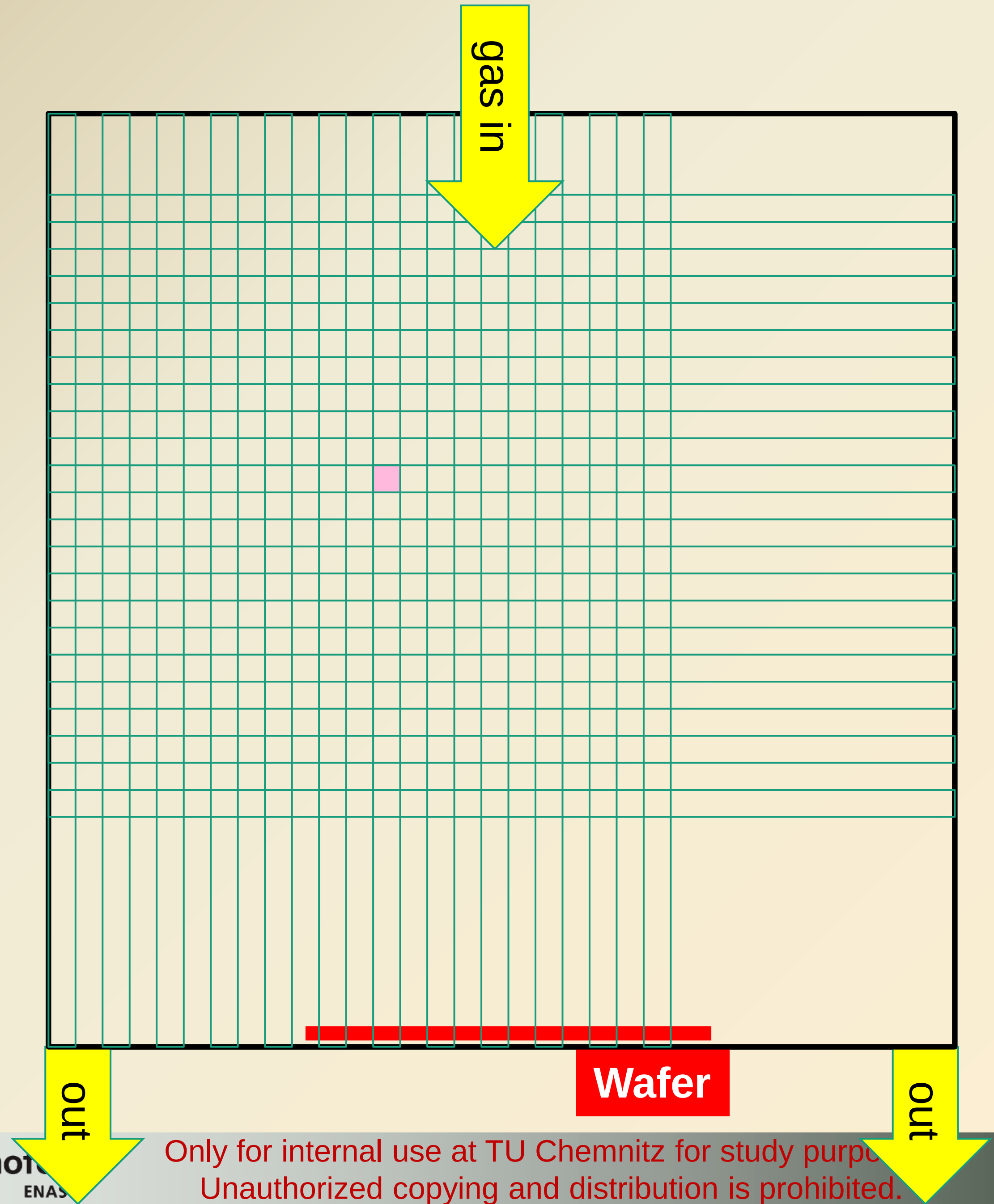
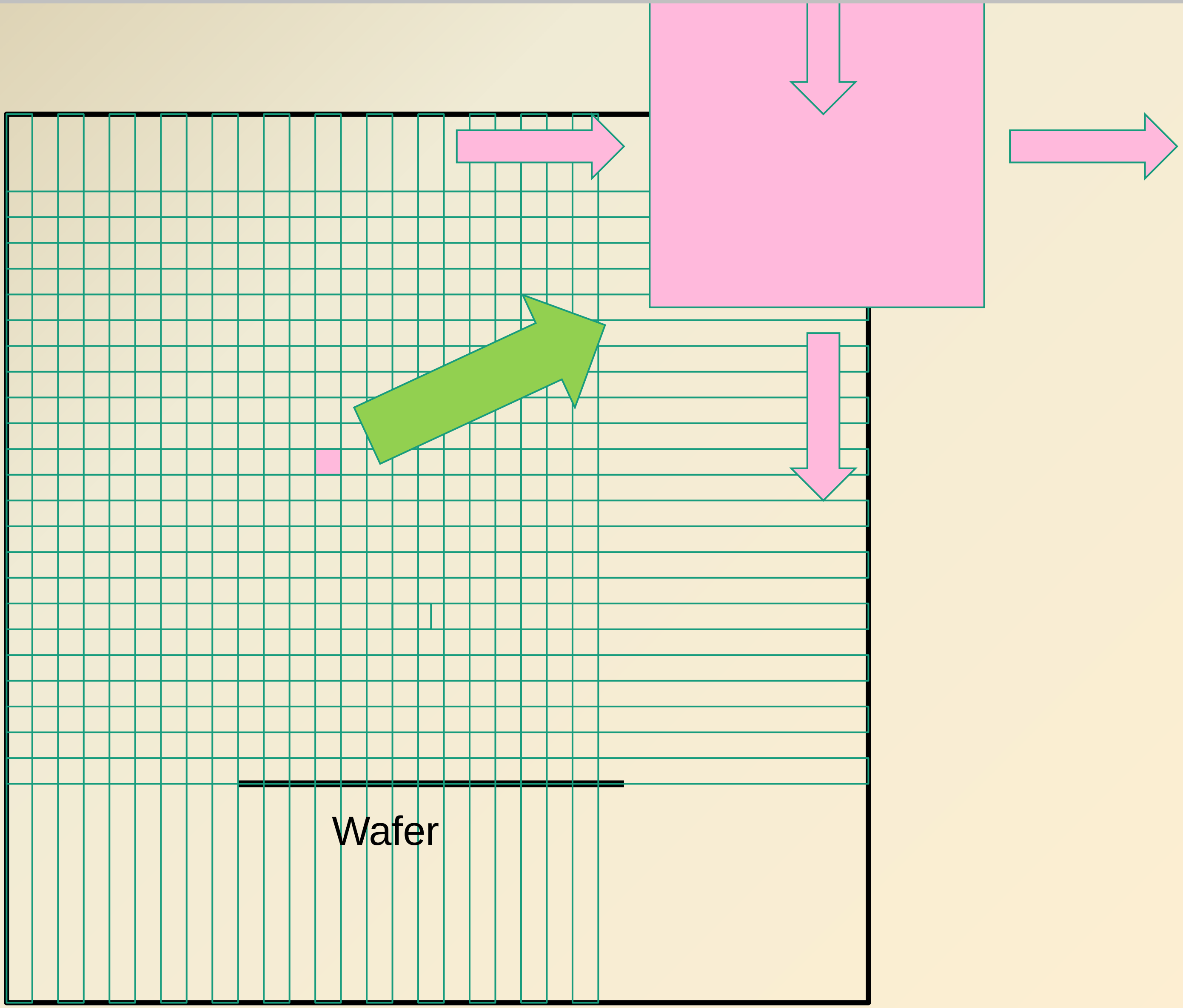
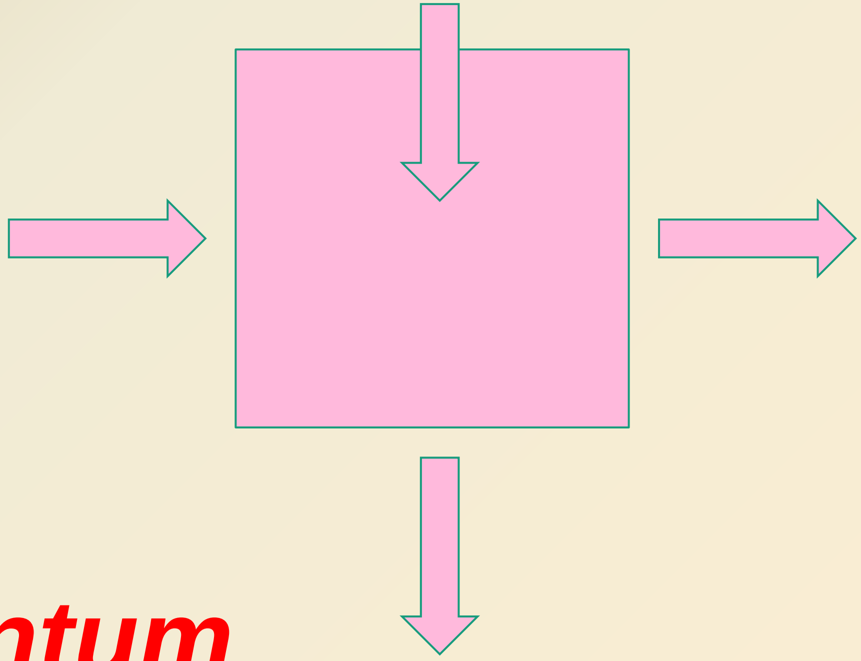
Reactor

1 Transport Simulation




gas in
Wafer
out
out


Wafer



Mass

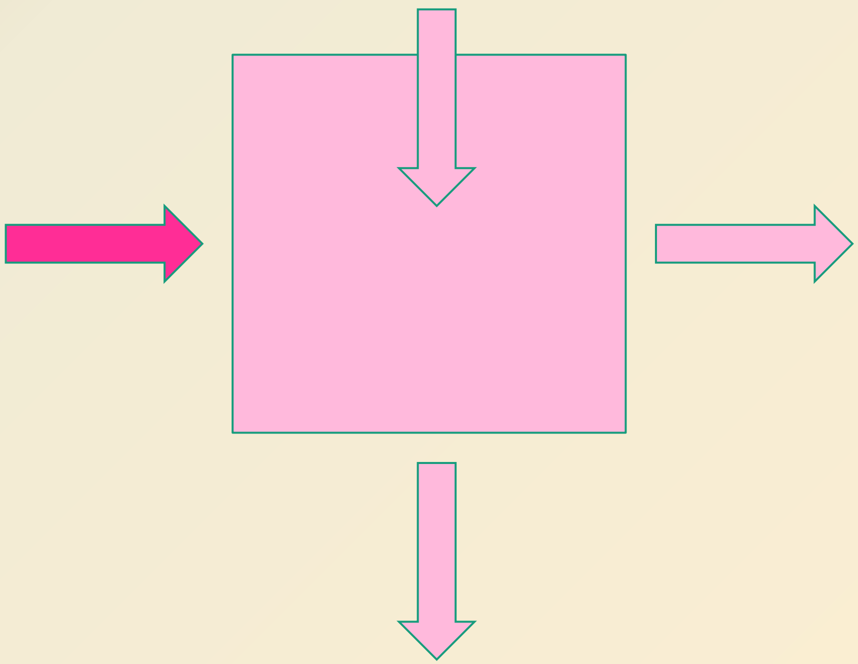
Momentum

Energy

Species *i = 1…n*

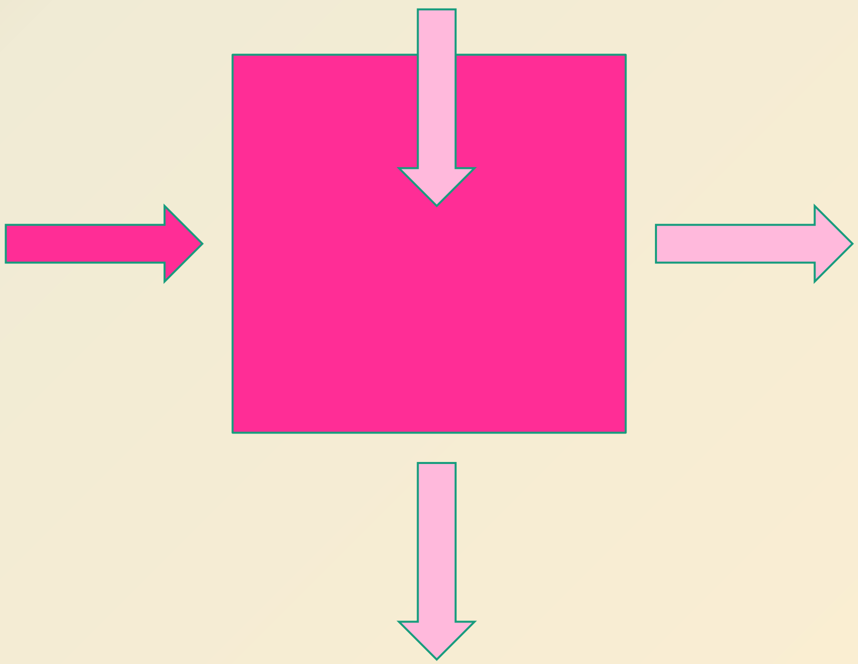
transient | convection | diffusion | source

$$\xi \, \frac{d}{dt}(\rho\phi) = -\xi \nabla (\rho \underline{\upsilon} \phi) + \nabla (\Gamma \nabla \phi) + S$$



transient **convection** **diffusion** **source**

$$\xi\, d/dt\,(\rho\phi) = -\,\xi\,\nabla\,(\rho\underline{\upsilon}\phi) + \nabla\,(\Gamma\,\nabla\,\phi) + S$$



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transient convection diffusion source

$$\xi \, d/dt\,(\rho\phi) = -\,\xi \nabla (\rho \underline{\upsilon} \phi) + \nabla (\Gamma \nabla \phi) + S$$

Continuity

Momentum

Energy

Species *i = 1...n*

transient convection diffusion source

$$\underset{=1}{\xi}\, d/dt\,(\rho\underset{=1}{\phi}) = -\underset{=1}{\xi}\,\nabla\,(\rho\underline{\upsilon}\underset{=1}{\phi}) + \nabla\,(\underset{=0}{\Gamma}\,\nabla\,\phi) + \underset{=0}{S}$$

$$d/dt\,(\rho\ ) = -\ \nabla\,(\rho\underline{\upsilon}\ )$$

Continuity

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transient convection diffusion source

$$\xi\, d/dt\,(\rho\phi) = -\,\xi\,\nabla\,(\rho\underline{\upsilon}\phi) + \nabla\,(\Gamma\,\nabla\,\phi) + S$$

=1   =1 $= \mu$ $= \underline{\upsilon}$

$$d/dt\,(\rho\underline{\upsilon}) = -\,\nabla\,(\rho\underline{\upsilon}\underline{\upsilon}) + \nabla\,(\mu\,\nabla\,\underline{\upsilon}) + S$$

Momentum

S=

$$\nabla\cdot\left(\mu(\nabla\underline{v})^{\dagger} + (\kappa - \tfrac{2}{3}\mu)(\nabla\cdot\underline{v})\underline{\underline{I}}\right) - \nabla P + \rho\underline{g}$$

dynamic viscosity of the gas mixture, *kg m⁻¹ s⁻²*

velocity vector, *m s⁻¹*

transposed vector

volume viscosity, *kg m⁻¹ s⁻¹*

unity tensor

pressure, *Pa*

S=

$$\nabla \cdot \left(\mu(\nabla \underline{v})^{\dagger} + (\kappa - \tfrac{2}{3}\mu)(\nabla \cdot \underline{v})\underline{\underline{I}}\right) - \nabla P + \rho \underline{g}$$

$$\nabla\left(\mu(\nabla \underline{\vartheta})\right)^{\dagger} + \left(k - \frac{2}{3}\mu\right)(\nabla \cdot \underline{\vartheta})\underline{\underline{I}} - \nabla P - \rho g$$

gravity vector, *(g_z = -9.81 m s⁻²)*

density, *kg m⁻³*

transient convection diffusion source

$$\underbrace{\xi}_{=c}\, \frac{d}{dt}(\rho \underbrace{\phi}_{=T}) = -\underbrace{\xi}_{=c}\, \nabla (\rho \underline{\upsilon} \phi) + \nabla (\underbrace{\Gamma}_{=\lambda} \nabla \underbrace{\phi}_{=T}) + S$$

Energy

$$c\, \frac{d}{dt}(\rho T) = -c\, \nabla (\rho \underline{\upsilon} T) + \nabla (\lambda \nabla T) + S$$

S=

$$\nabla \cdot \left(RT \sum_{i=1}^{N} \frac{\mathbf{D}_i^T}{m_i} \nabla (\ln f_i) \right) + \sum_{i=1}^{N} \left(\frac{H_i}{m_i} \nabla \cdot \underline{j}_i - \sum_{k=1}^{K} H_i \nu_{ik} (\mathcal{R}_k^g - \mathcal{R}_{-k}^g) \right)$$

universal gas constant = 8.314 $J\ mole^{-1}\ K^{-1}$

Temperature, K

number of gaseous species

multicomponent thermal diffusion coefficient of species i, $kg\ m^{-1}\ s^{-1}$

mole mass of species i

species i mole fraction

S=

$$\nabla \cdot \left(RT \sum_{i=1}^{N} \frac{D_i^T}{m_i} \nabla (\ln f_i) \right) + \sum_{i=1}^{N} \left(\frac{H_i}{m_i} \nabla \cdot j_i - \sum_{k=1}^{K} H_i \nu_{ik} (\mathcal{R}_k^g - \mathcal{R}_{-k}^g) \right)$$

diffusive mass flux vector, $kg\ m^{-2}\ s^{-1}$

molar enthalpy, $J\ mole^{-1}$

reverse reaction rate of the k^{th} gas phase reaction, mole $m^{-3}\ s^{-1}$

foreward reaction rate of the k^{th} gas phase reaction, mole $m^{-3}\ s^{-1}$

stoicmetric coefficient of the ith gaseous species in the k^{th} gas phase reaction

number of gas phase reactions

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ZfM Fraunhofer ENAS

transient		convection		diffusion	source
$\xi \, d/dt\,(\rho\phi)$	$=$	$-\,\xi\,\nabla\,(\rho\underline{\upsilon}\phi)$	$+$	$\nabla\,(\Gamma\,\nabla\,\phi)$	$+\,S$

$\xi = 1$, $\phi = \omega_i$ (transient); $\xi = 1$, $\phi = \omega_i$ (convection); $\Gamma = \rho D_i$, $\phi = T$ (diffusion)

Species $i = 1 \ldots n$

$$d/dt\,(\rho\omega_i) = -\,\nabla\,(\rho\underline{\upsilon}\omega_i) + \nabla\,(\rho D_i\,\nabla\,\omega_i) + S$$

$S=$

$$\nabla\cdot(\mathbb{D}_i^T\nabla(\ln T) + \nabla\cdot(\rho\omega_i\mathbb{D}_i\nabla(\ln m)$$
$$-\nabla\cdot\left(m\omega_i\mathbb{D}_i\sum_{j=1}^{N}\frac{\underline{j}_j}{m_jD_{ij}}\right)$$
$$+m_i\sum_{k=1}^{K}\nu_{ik}\left(k_k\prod_{i=1}^{N}c_i^{\|-\nu_{ik}\|}-k_{-k}\prod_{i=1}^{N}c_i^{\|\nu_{ik}\|}\right)$$

multicomponent thermal diffusion coefficient of species *i*, *kg m*$^{-1}$ *s*$^{-1}$

species *i* mass fraction

effective multicomponent diffusion coefficient of species *i*, *kg m*^{2} *s*$^{-1}$ *kg*

Temperature, *K*

density, *kg m*$^{-3}$

average mole mass, kg

number of gaseous species

specific heat of the gas mixture, J *kg*$^{-1}$ *K*$^{-1}$

S=

$$\nabla \cdot (\mathbb{D}_i^T \nabla(\ln T)) + \nabla \cdot (\rho \omega_i \mathbb{D}_i \nabla(\ln m)) \\ -\nabla \cdot \left(m \omega_i \mathbb{D}_i \sum_{j=1}^{N} \frac{j_j}{m_j D_{ij}} \right) \\ + m_i \sum_{k=1}^{K} \nu_{ik} \left(k_k \prod_{i=1}^{N} c_i^{\|-\nu_{ik}\|} - k_{-k} \prod_{i=1}^{N} c_i^{\|\nu_{ik}\|} \right)$$

molar mass of species *i*, *kg mole*$^{-1}$

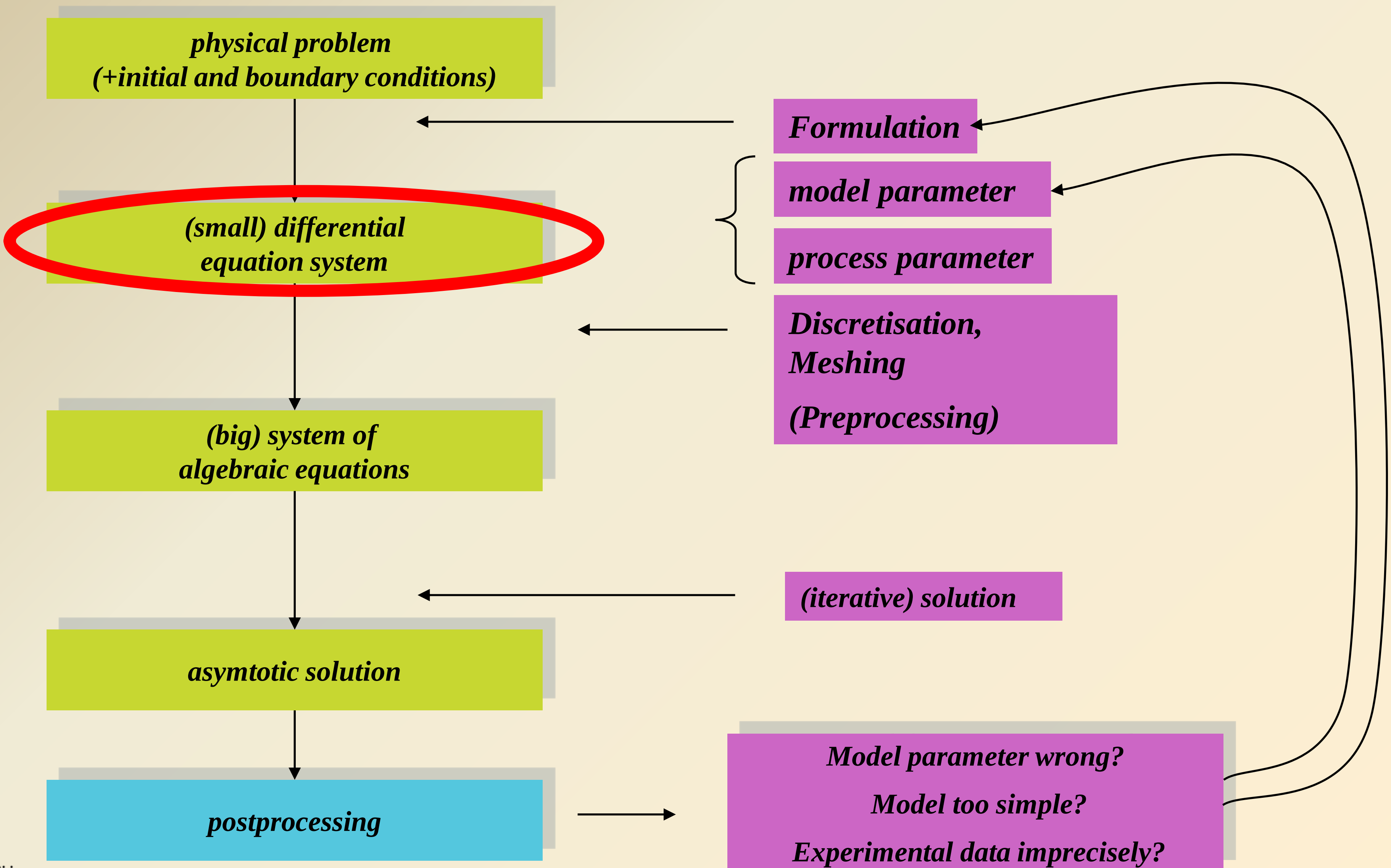
reverse reaction rate constant for the of the kth *homogeneous in m*^{3} *, mole and s dep. on the reaction order*

foreward reaction rate constant for the of the kth *homogeneous in m*^{3} *, mole and s dep. on the reaction order*

number of gas phase reactions

stoicmetric coefficient of the ith gaseous species in the kth *gas phase reaction*

Mathematical methods



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Fraunhofer ENAS

General Transport Equation

transient — *convection* — *diffusion* — *source*

$$\xi \, d/dt\,(\rho\phi) = -\,\xi\,\nabla\,(\rho\underline{\upsilon}\phi) + \nabla\,(\Gamma\,\nabla\,\phi) + S$$

Continuity

$$d/dt\,(\rho) = -\,\nabla\,(\rho\underline{\upsilon})$$

$$d/dt\,(\rho\underline{\upsilon}) = -\,\xi\,\nabla\,(\rho\underline{\upsilon}\underline{\upsilon}) + \nabla\,(\mu\,\nabla\,\underline{\upsilon}) + S$$

$$c\,d/dt\,(\rho T) = -\,c\,\nabla\,(\rho\underline{\upsilon}T) + \nabla\,(\lambda\,\nabla\,T) + S$$

$$d/dt\,(\rho\omega_i) = -\,\nabla\,(\rho\underline{\upsilon}\omega_i) + \nabla\,(\rho D_i\,\nabla\,\omega_i) + S$$

Momentum $S=$

$$\nabla \cdot \left(\mu(\nabla\underline{v})^{\dagger} + (\kappa - \tfrac{2}{3}\mu)(\nabla\cdot\underline{v})\underline{\underline{I}}\right) - \nabla P + \rho\underline{g}$$

Energy $S=$

$$\nabla \cdot \left(RT\sum_{i=1}^{N}\frac{\mathbf{D}_i^T}{m_i}\nabla(\ln f_i)\right) + \sum_{i=1}^{N}\left(\frac{H_i}{m_i}\nabla\cdot\underline{j}_i - \sum_{k=1}^{K}H_i\nu_{ik}(\mathcal{R}_k^g - \mathcal{R}_{-k}^g)\right)$$

Species $S=$

$$\nabla\cdot(\mathbb{D}_i^T\nabla(\ln T) + \nabla\cdot(\rho\omega_i\mathbb{D}_i\nabla(\ln m)) - \nabla\cdot\left(m\omega_i\mathbb{D}_i\sum_{j=1}^{N}\frac{\underline{j}_j}{m_jD_{ij}}\right) + m_i\sum_{k=1}^{K}\nu_{ik}\left(k_k\prod_{i=1}^{N}c_i^{\|-\nu_{ik}\|} - k_{-k}\prod_{i=1}^{N}c_i^{\|\nu_{ik}\|}\right)$$

$\xi\, d/dt\,(\rho\phi) = \; - \xi \nabla (\rho \underline{\upsilon} \phi) \;\; + \nabla (\Gamma \nabla \phi) + S$

$d/dt\,(C) = \qquad \nabla (D \nabla C)$

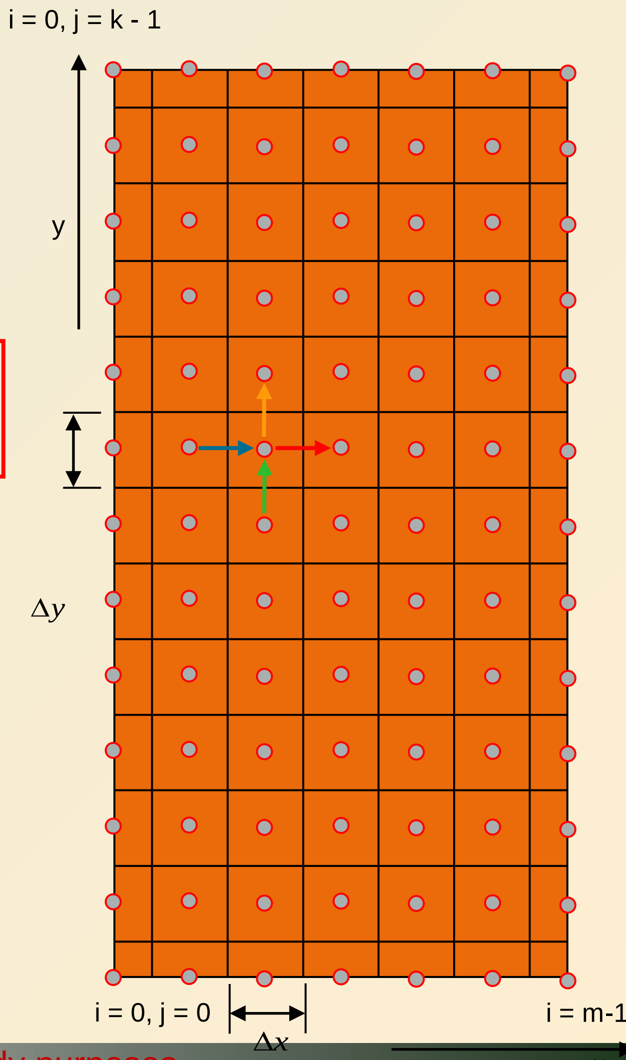
2 Dim: $D \nabla C = D\,(dC/dx + dC/dx)$

$$j = -\frac{D(C^n_{i,j+1} - C^n_{i,j})}{\Delta y}$$

$$j = -\frac{D(C^n_{i,j} - C^n_{i-1,j})}{\Delta x} \qquad j = -\frac{D(C^n_{i+1,j} - C^n_{i,j})}{\Delta x}$$

$$j = -\frac{D(C^n_{i,j} - C^n_{i,j-1})}{\Delta y}$$

$$div(\vec{j}) = \frac{\oint \vec{j}\, d\vec{s}}{A} = \frac{(\boxed{j} - \boxed{j})\Delta y + (\boxed{j} - \boxed{j})\Delta x}{\Delta x \Delta y}$$

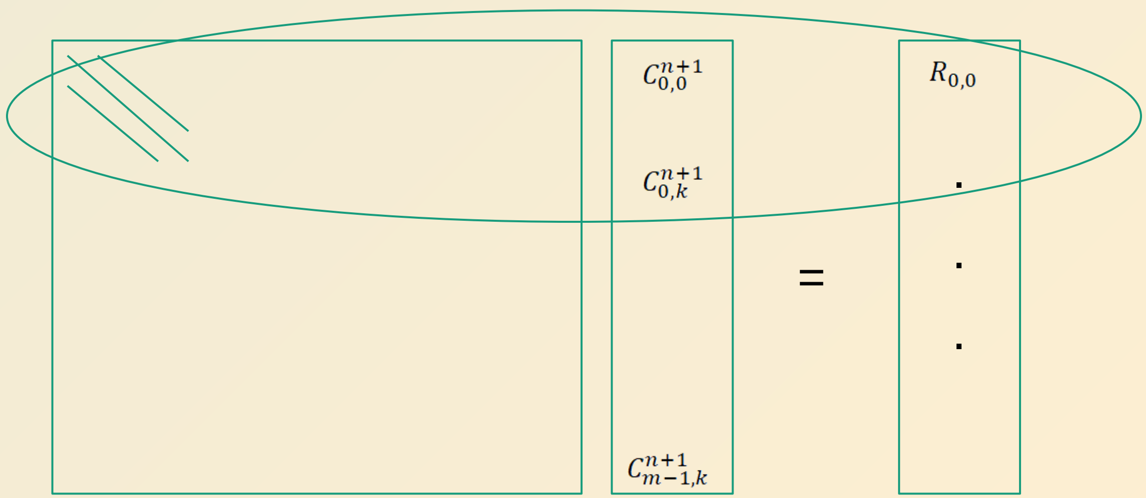


$$\frac{\partial C}{\partial t} = -div(j) = D\left(\frac{\left(C_{i+1,j}^{n+1} - 2C_{i,j}^{n+1} + C_{i-1,j}^{n+1}\right)}{\Delta x^2} + \frac{\left(C_{i,j+1}^{n+1} - 2C_{i,j}^{n+1} + C_{i,j-1}^{n+1}\right)}{\Delta y^2}\right)$$

5-points equation

$$C_{i,j}^{n+1} = C_{i,j}^{n} + \Delta t \cdot D\left(\frac{\left(C_{i+1,j}^{n+1} - 2C_{i,j}^{n+1} + C_{i-1,j}^{n+1}\right)}{\Delta x^2} + \frac{\left(C_{i,j+1}^{n+1} - 2C_{i,j}^{n+1} + C_{i,j-1}^{n+1}\right)}{\Delta y^2}\right)$$

1d: tri diagonal mx

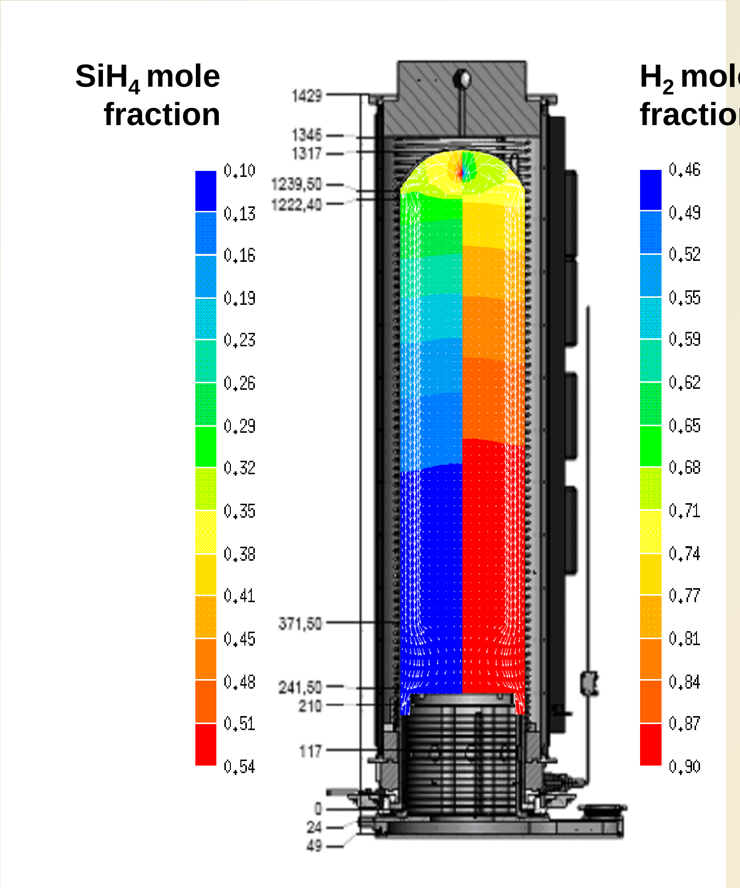


Improvement of

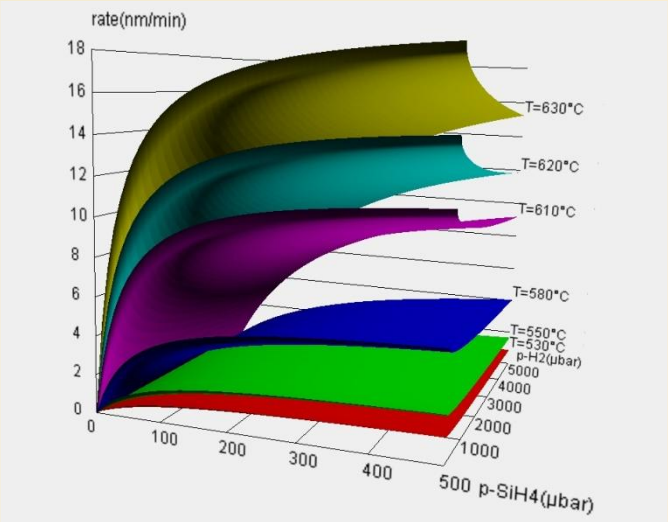
- deposition rates
- uniformity

by **optimization** of

- process conditions
- reactor configuration

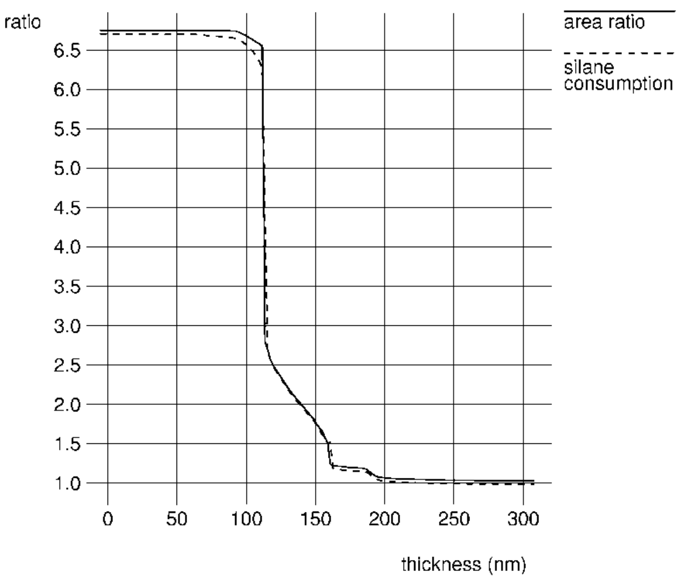


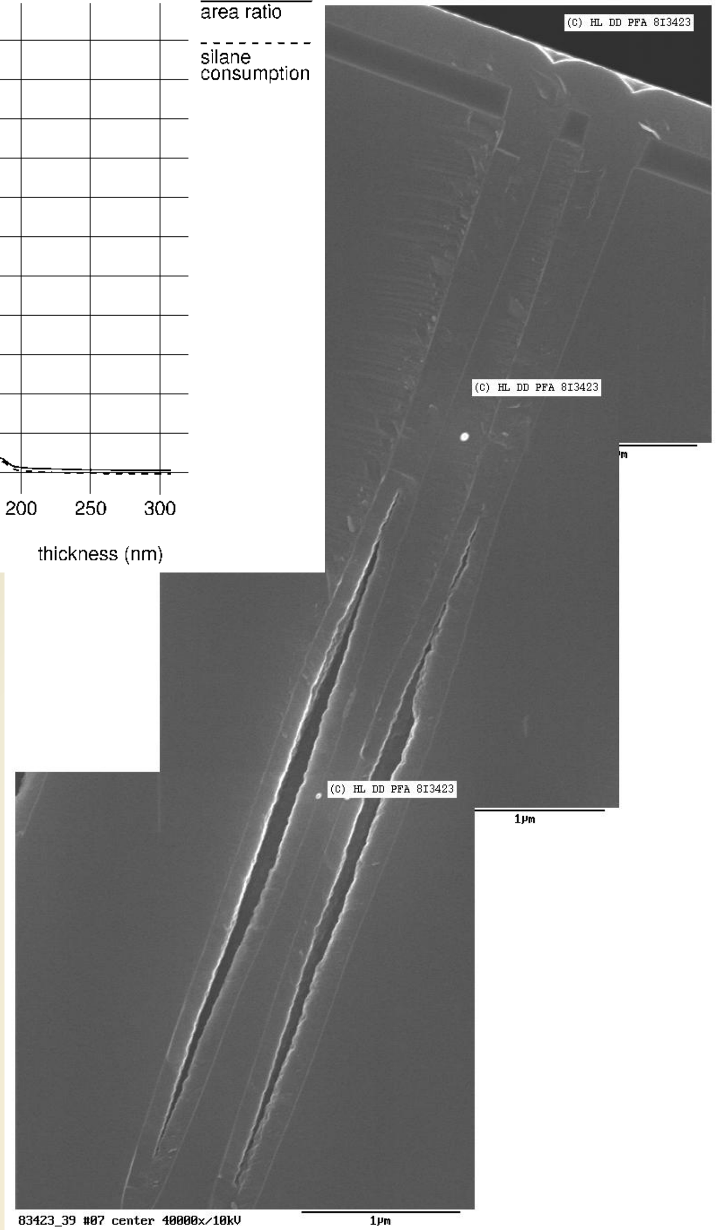
Flow pattern and distributions of SiH_4 and H_2 mole fractions inside the reactor for silicon deposition at 630 ºC, 200 µbar, 200 sccm SiH_4, 0 sccm H_2.

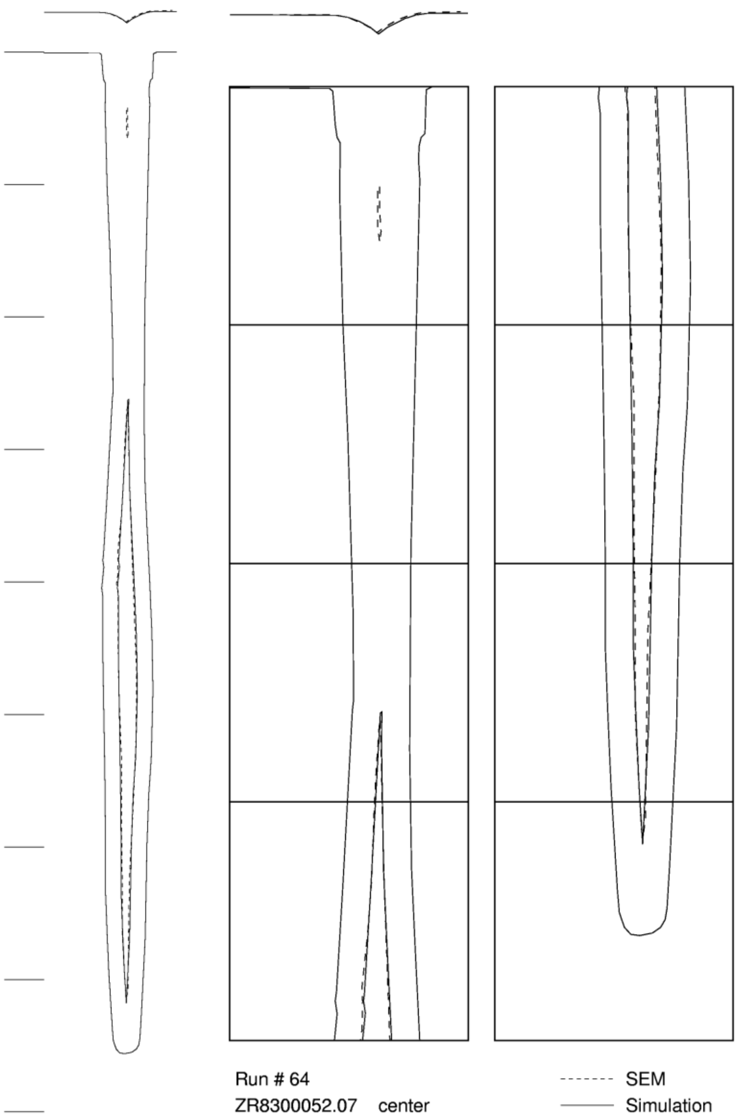


Dependence of deposition rates on the local partial pressures of SiH_4 and H_2 for different deposition temperatures

Reactor Scale: Deep trenches (Multi-step trench filling with As doped poly)







Advanced Integ