TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

Space Mapping Optimization & Applications

Model Order Reduction, Durham 2017

René Pinnau

Fraunhofer ITWM Institut Techno- und Wirtschaftsmathematik

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Fraunhofer ITWM

- Budget of 22 Million Euro
- more than 200 scientists

Experience at the ITWM

Many industrial problems require the usage of optimization tools

<u>Problem 1:</u> Black-box tools are too slow

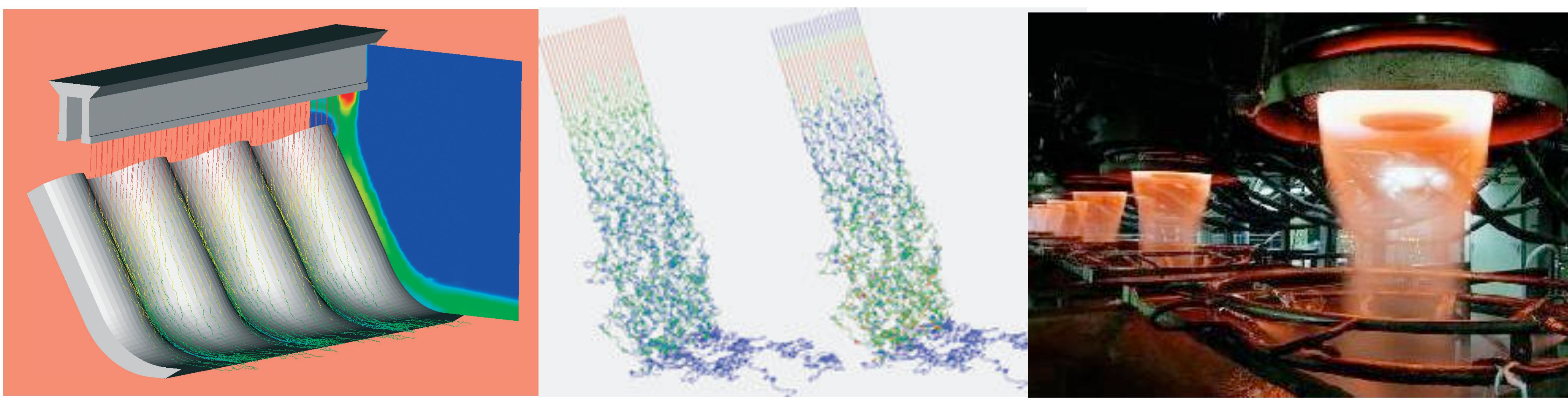
<u>Problem 2:</u> Engineers do not like adjoints

<u>Solution:</u> Space-Mapping Optimization

Optimal Control of Particles in Fluids

Optimal Control of Particles

- Control of particles with mass based on ficticious-domain techniques
- Control of mass-free oriented particles based on Jeffery's equation
- Control of mass-free particles in turbulent fluids



The Model Hierarchies

Particles with mass	Turbulent Navier-Stokes
Mass-free particles with orientation	Laminar Navier-Stokes
Particles without mass	Stokes Flow

The Particle Model

Assumptions:
The particles are small, spherical and light

$$\begin{aligned} dr_j(t) &= \bar{v}(r_j(t),t)\,dt + a_T(r_j(t),t)\,dW_t \\ a_T &= \sqrt{\frac{k\,\tau_T}{Re_T}}, \qquad \tau_T = k/\varepsilon \end{aligned}$$

Stochastic ODE with Brownian motion

Drift is given by the mean velocity

Marheineke, Wegener

Stochastic Design Problem

Minimize

$$J(\mathbb{E}[\mathbf{P}], \mathbf{u}; \mathbf{P}^\star, \mathbf{u}^\star) = \frac{1}{2}\left(\lambda_1 \int_0^T (\mathbb{E}[\mathbf{P}] - \mathbf{P}^\star)^2 \, dt + \lambda_2((\mathbb{E}[\mathbf{P}] - \mathbf{P}^\star)(T))^2\right) + \frac{\alpha}{2}\int_\Upsilon (\mathbf{u} - \mathbf{u}^\star)^2 \, d\mathbf{x}dt$$

subject to the stochastic fluid-particle model.

Monte-Carlo-Simulations are needed!

Adjoints are hard to derive!

Numerical effort exorbitant!

Marheineke, P., Resendiz

Space Mapping Idea

For the optimization we use the space mapping technique:

Fine Model

$$\begin{aligned} f(u), &\quad u \in U \\ F(u) &= \|f(u) - y\| \\ u^* &= \mathrm{argmin} F(u) \end{aligned}$$

Coarse Model

$$\begin{aligned} c(z), &\quad z \in U \\ C(z) &= \|c(z) - y\| \\ z^* &= \mathrm{argmin} C(z) \end{aligned}$$

$$p : U \to U, \quad \mathrm{argmin}_z \ \|c(z) - f(u)\|$$

Refs.: Bandler et al. 1994 —

Space Mapping Setup

➡ Fine model:
stationary k-ε-model + stochastic particle model

➡ Coarse model:
Navier-Stokes equations, small Reynolds number,
ODE particle model

$$
\begin{aligned}
(\mathbf{v}\cdot\nabla)\mathbf{v} &= -\nabla p + \frac{1}{\mathrm{Re}}\triangle\mathbf{v} + \mathbf{u}, \qquad \nabla\cdot\mathbf{v} = 0 \quad \text{in } \Omega \\
\mathbf{v} = \mathbf{v}_{\mathrm{in}} \ \text{ on } \partial\Omega_{\mathrm{in}}, \qquad \mathbf{v} &= \mathbf{0} \ \text{ on } \partial\Omega_{\mathrm{w}}, \qquad \frac{1}{\mathrm{Re}}\mathbf{n}\cdot\nabla\mathbf{v} - p\mathbf{n} = \mathbf{0} \ \text{ on } \partial\Omega_{\mathrm{out}} \\
\partial_t \mathbf{p_j}(t) &= \mathbf{v}(\mathbf{p_j}(t)) \ \text{ in } (0,T], \qquad \mathbf{P}(0) = \mathbf{P_0}
\end{aligned}
$$

Fully deterministic!

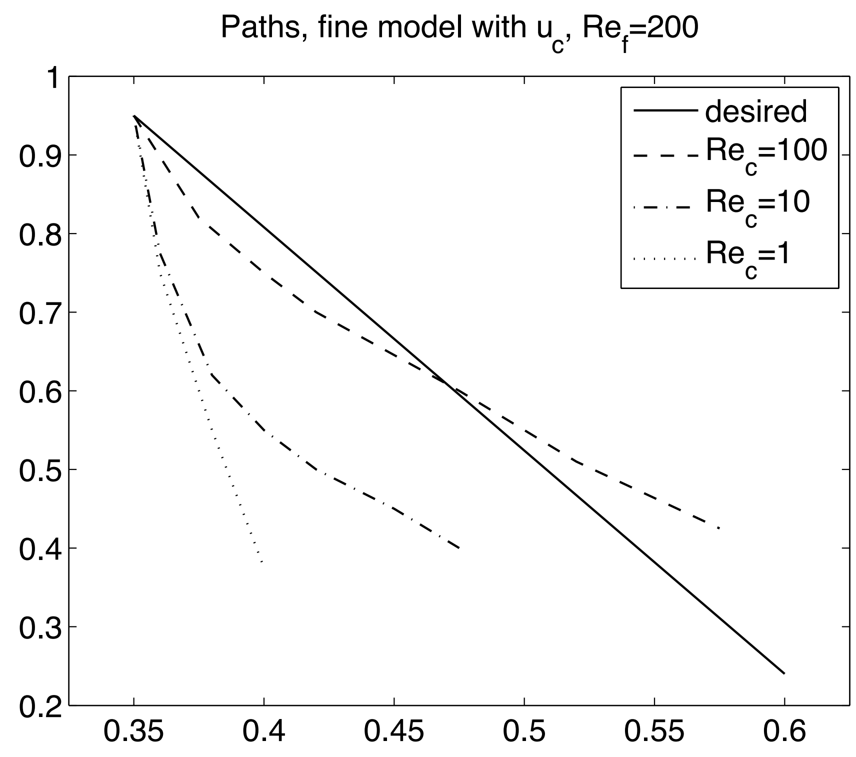
Space Mapping Algorithm

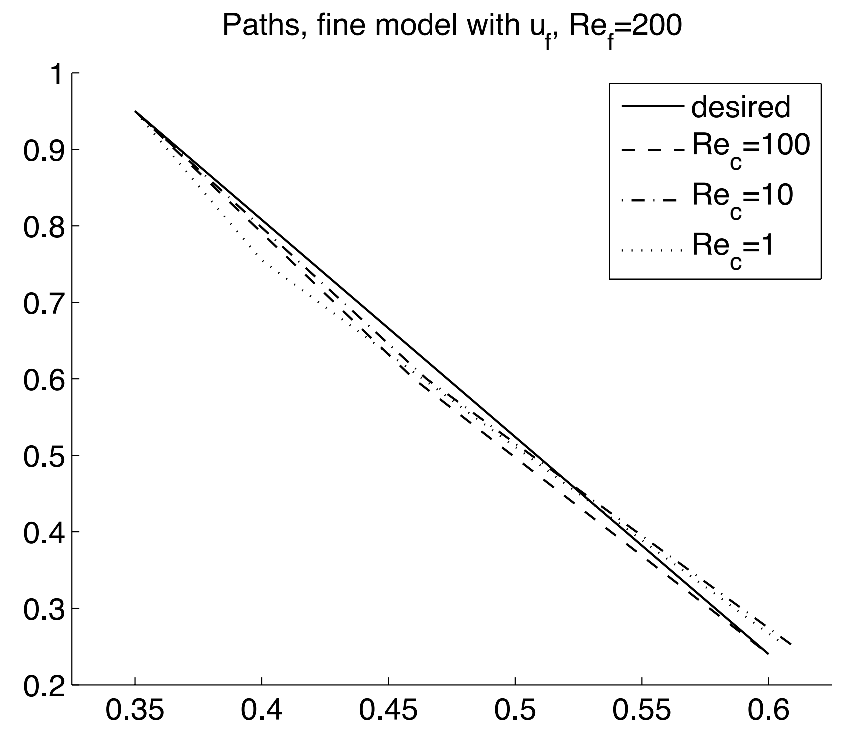
Agressive Space Mapping Algorithm:

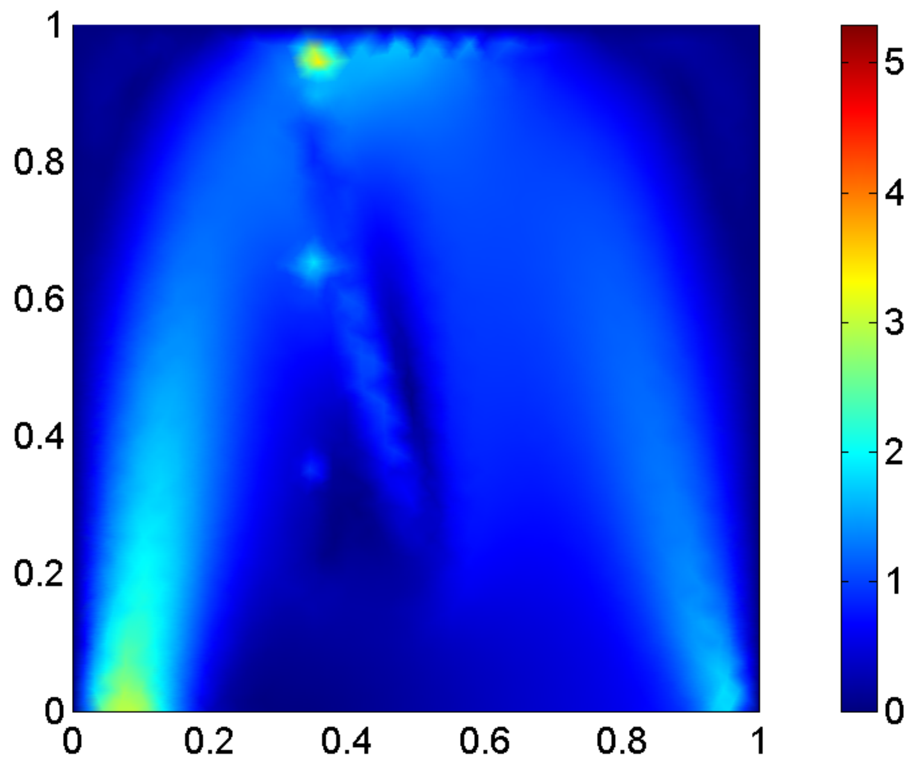
1. Set $u_0 = z^* = \operatorname{argmin}_z \|c(z) - y_{data}\|, B_0 = I, k = 0$
2. While $\|p(u_k) - z^*\| > \text{tolerance}$
3. Solve $B_k h_k = -(p(u_k) - z^*)$ to get h_k
4. Set $u_{k+1} = u_k + h_k$
5. Set $B_{k+1} = B_k + \dfrac{p(u_{k+1}) - z^*}{h_k^T h_k} h_k^T, \quad k = k+1$

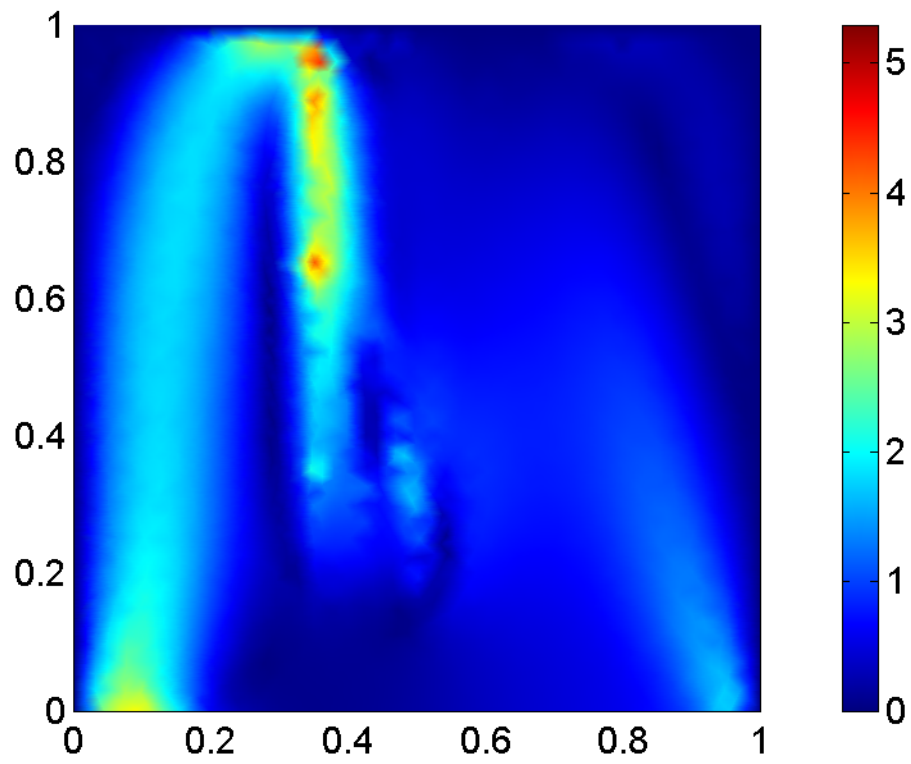
Hemker, et al. 2006

Numerical Results





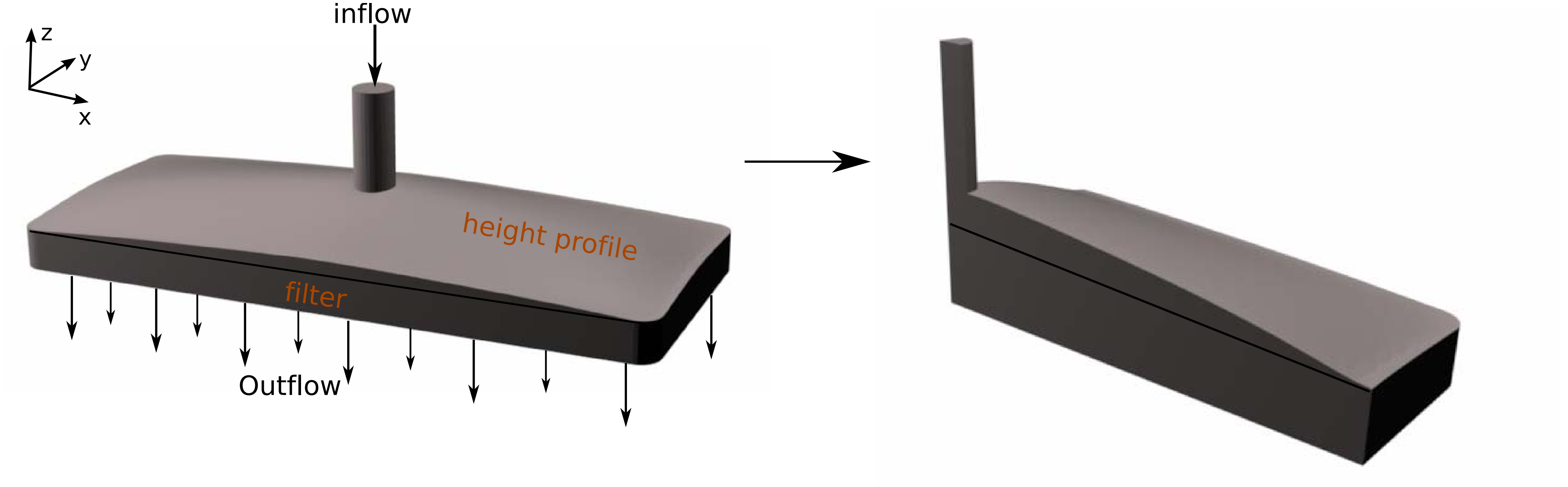




Optimal Design of Filters

A Shape Design Problem

<u>Design Goal:</u> Find a shape such that the mass flux is prescribed and some wall shear stresses are fixed



The Model Hierarchy

Laminar Navier-Stokes

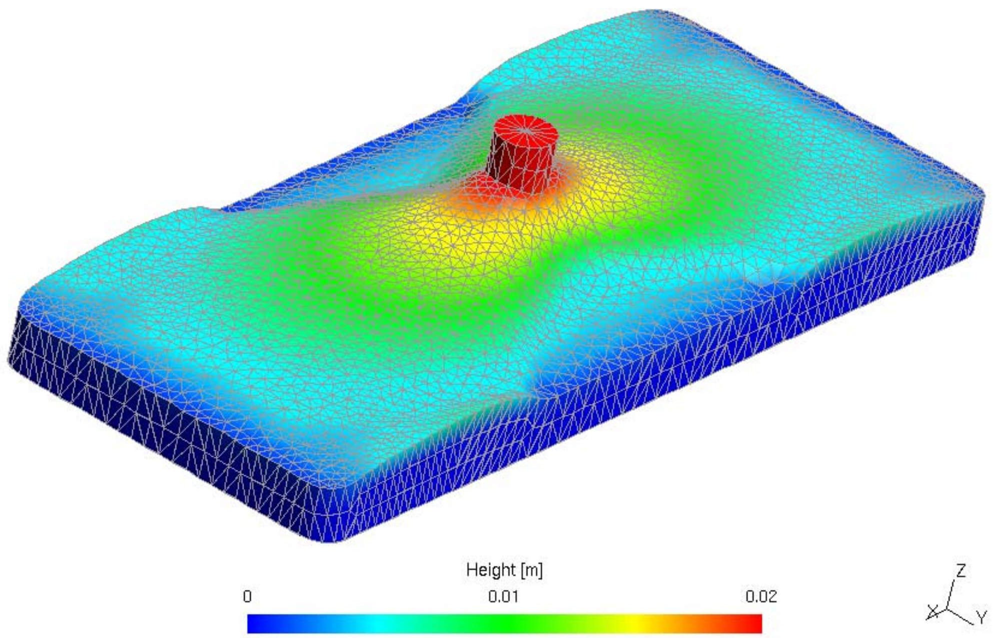
Stokes Flow (3d)

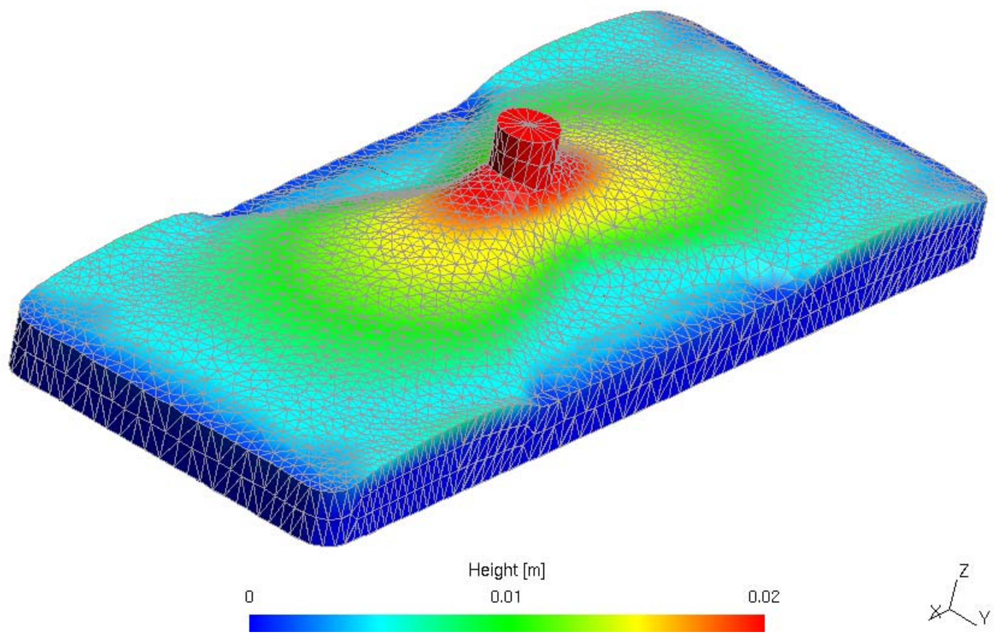
Stokes Flow (2d)

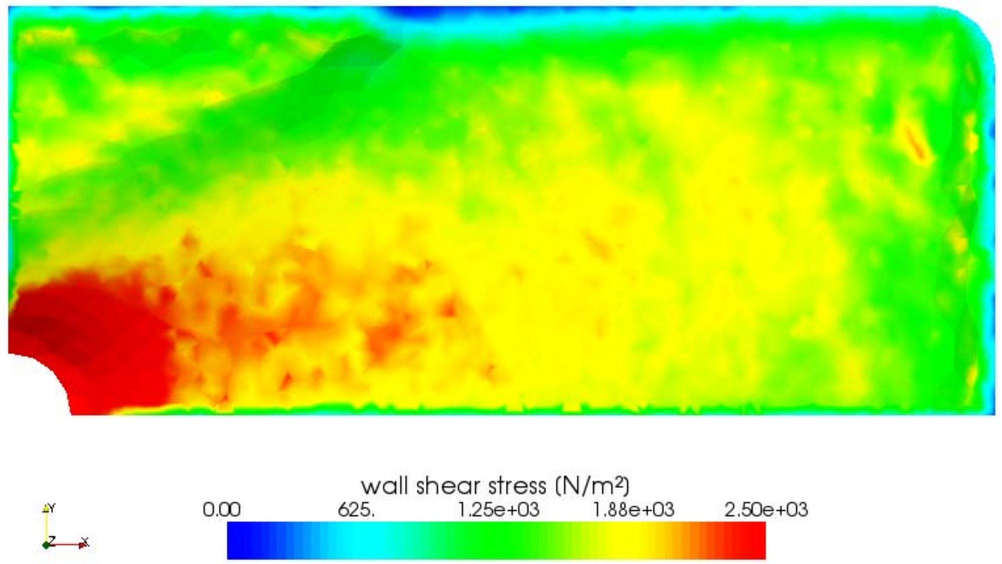
Numerical Results

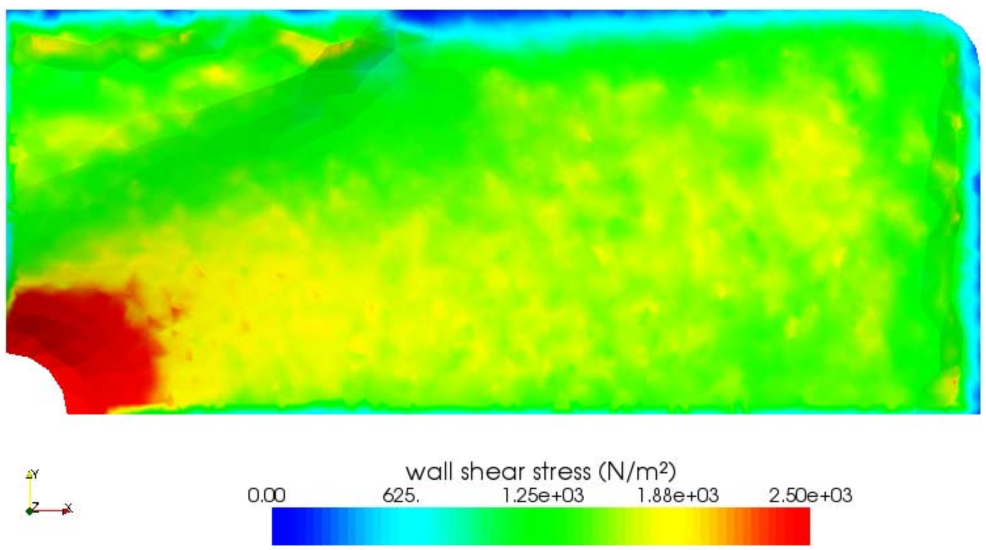
First Iterate

Last Iterate







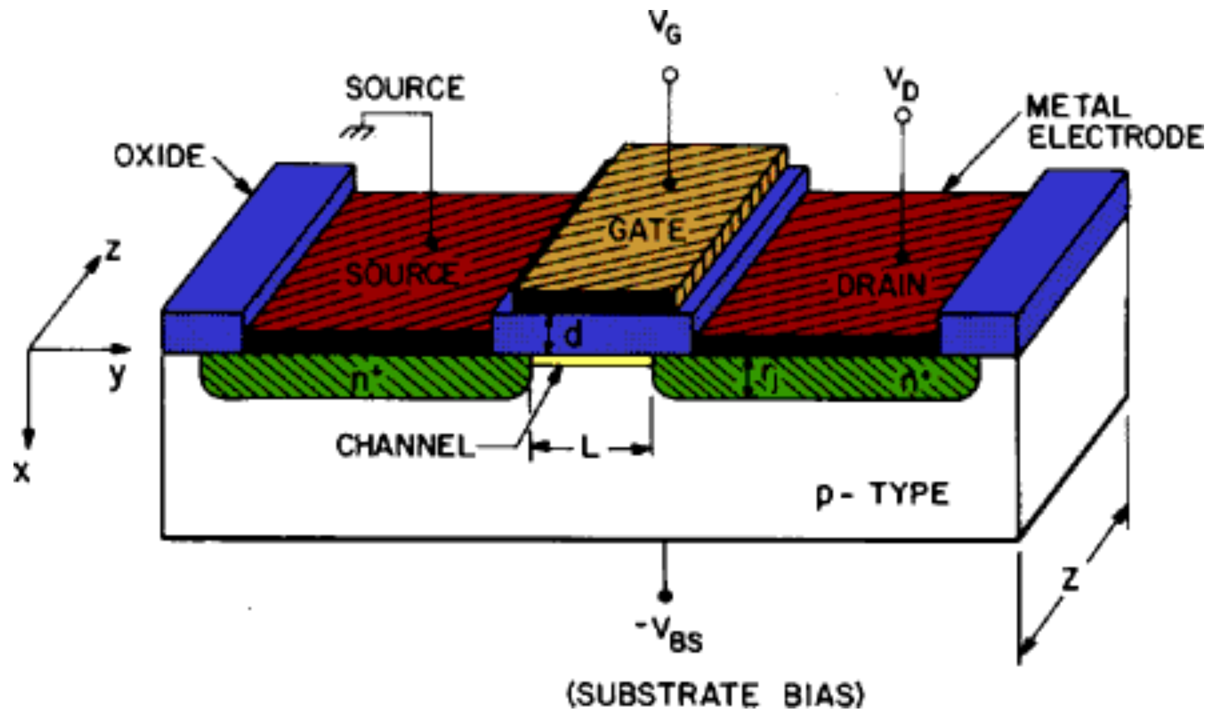


Optimal Semiconductor Design

The Semiconductor Design Problem

Design Goal: Find a doping profile such that we have an higher/lower current in the on/off state

Necessary for miniaturization, performance increase and better energy consumption



The Model Hierarchy

Boltzmann Eq.

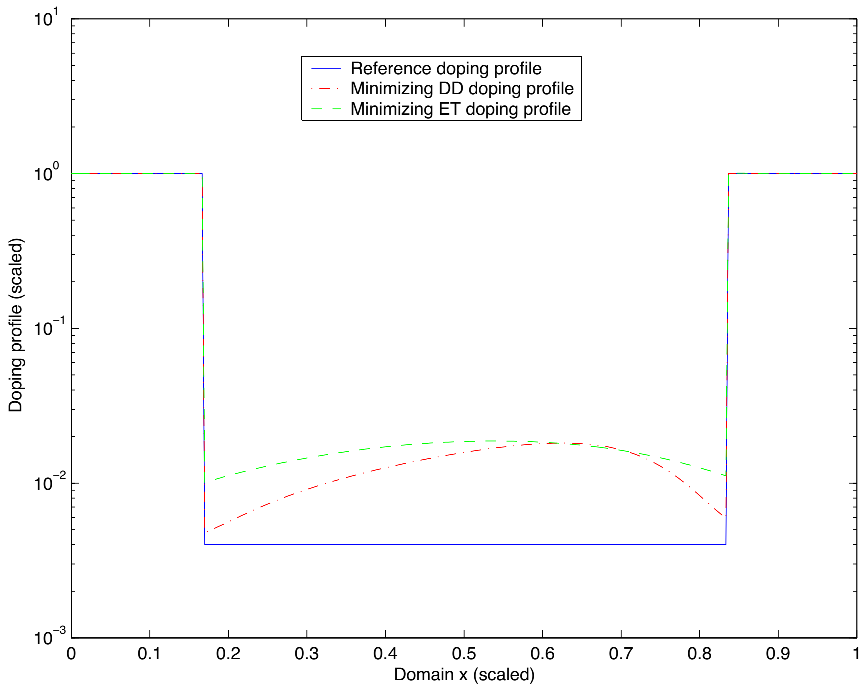
Hydrodynamic Eqs.

Energy-Transport Model

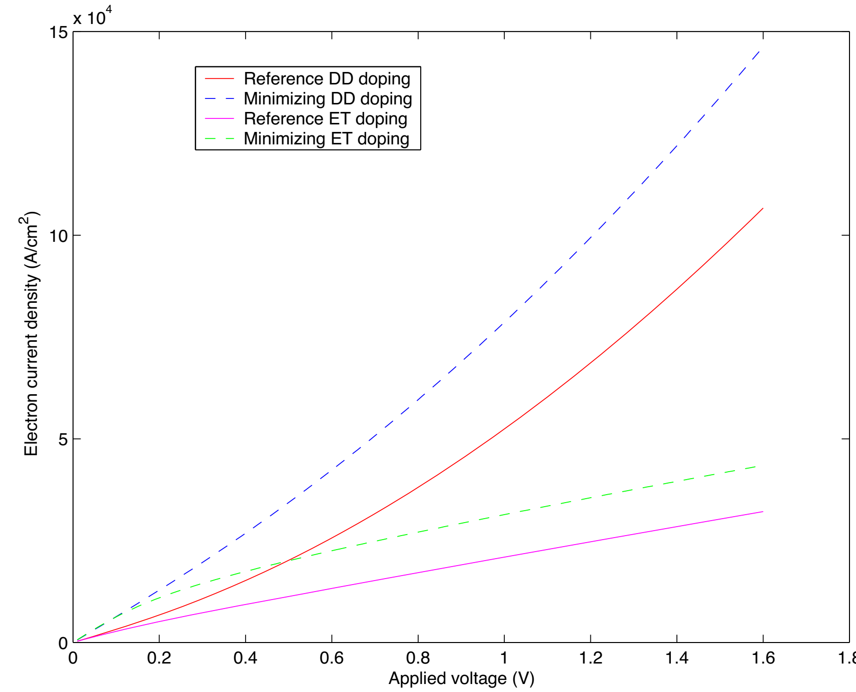
Drift-Diffusion Eqs.

Numerical Results

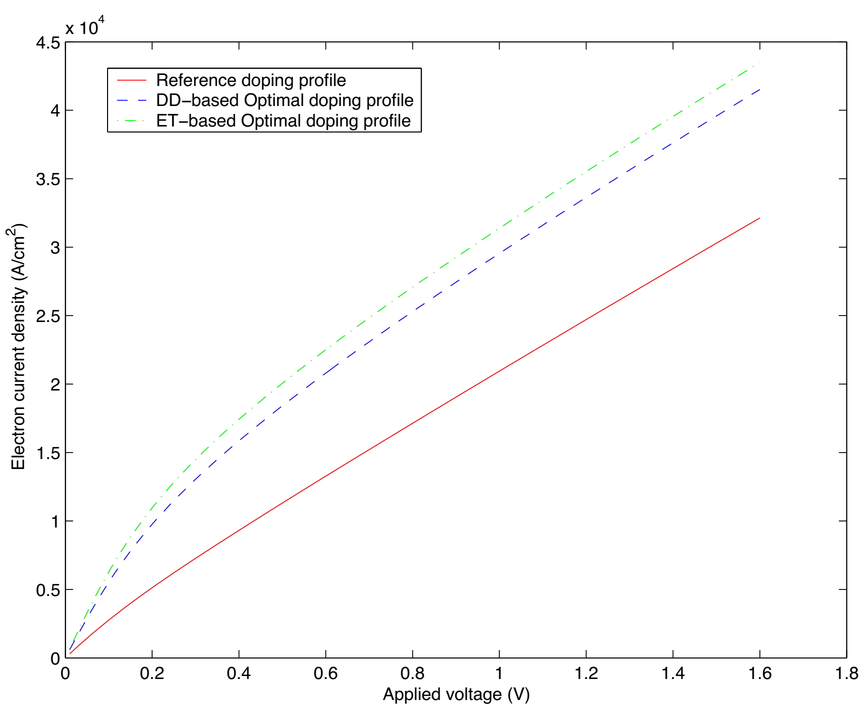
Optimization Results



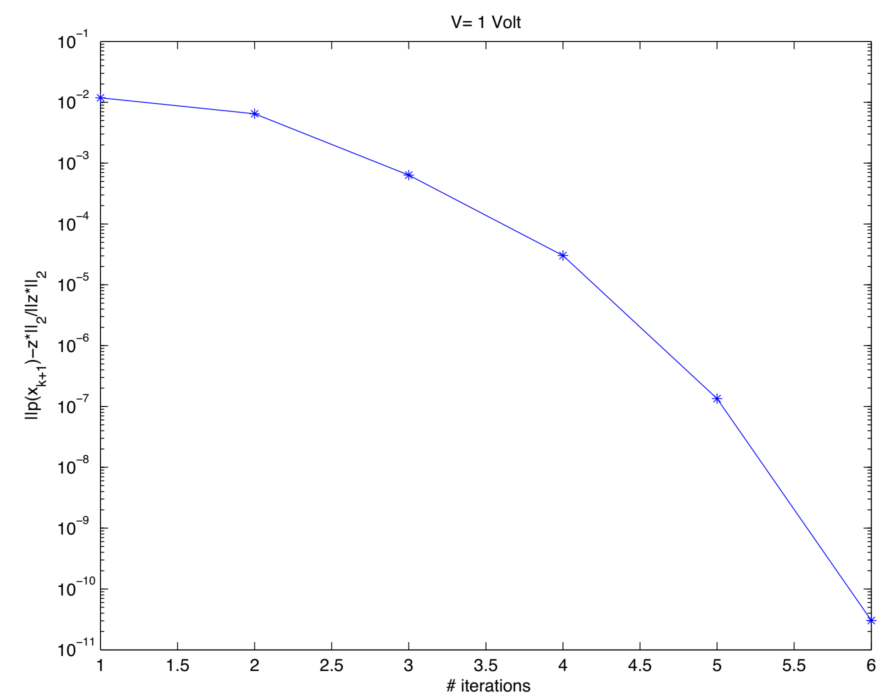
IVCs



DD in ET



Convergence of ASM



Drago, P.