Numerical Simulations of the Screen-Printing Process for Solar Cell Metallization

DPG Conference

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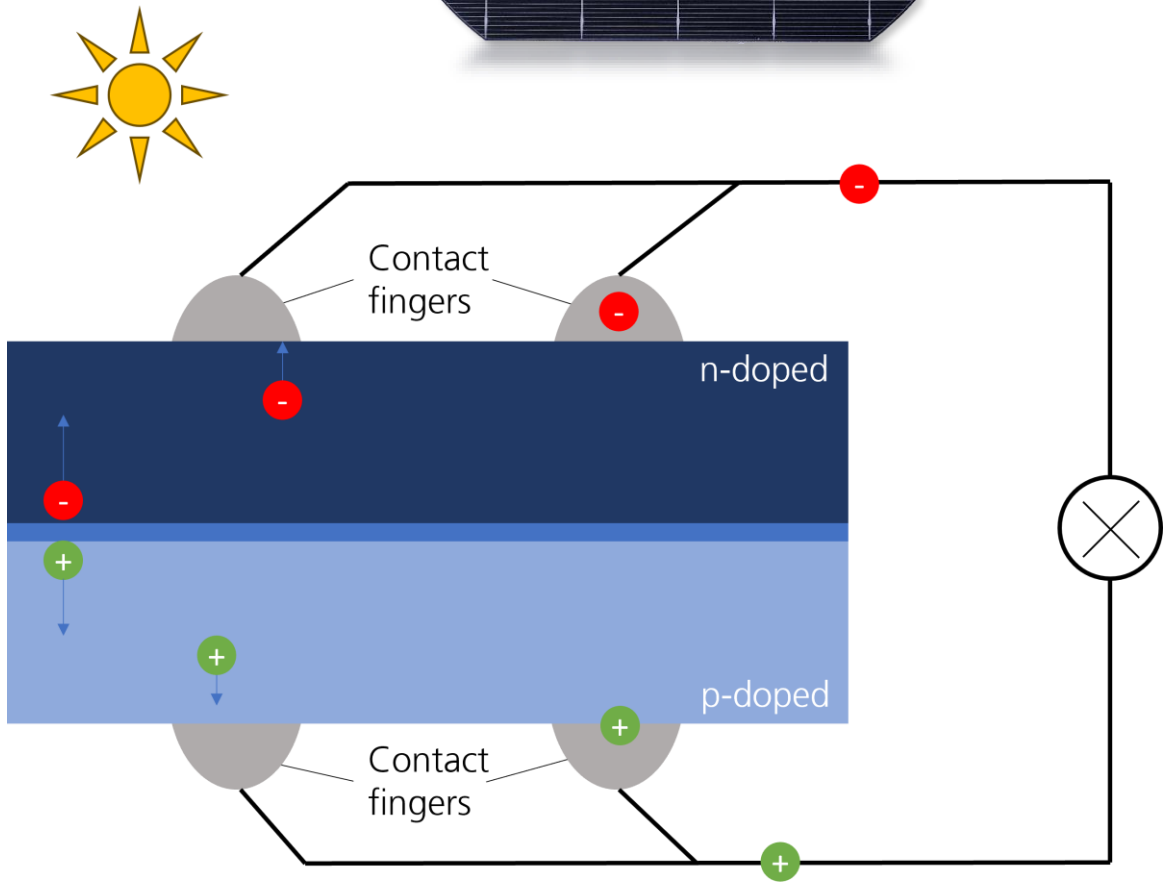
Metallization of Si-Solar Cells

Background

- Conducting electrodes on front and rear
- Extraction of electrical energy
- Mostly silver contact fingers due to high conductivity
  - 10% of global silver production is used for PV [1]
  - Most expensive non-Si material in solar cell production



[1] The Silver Institute, "World Silver Survey 2023," 2023

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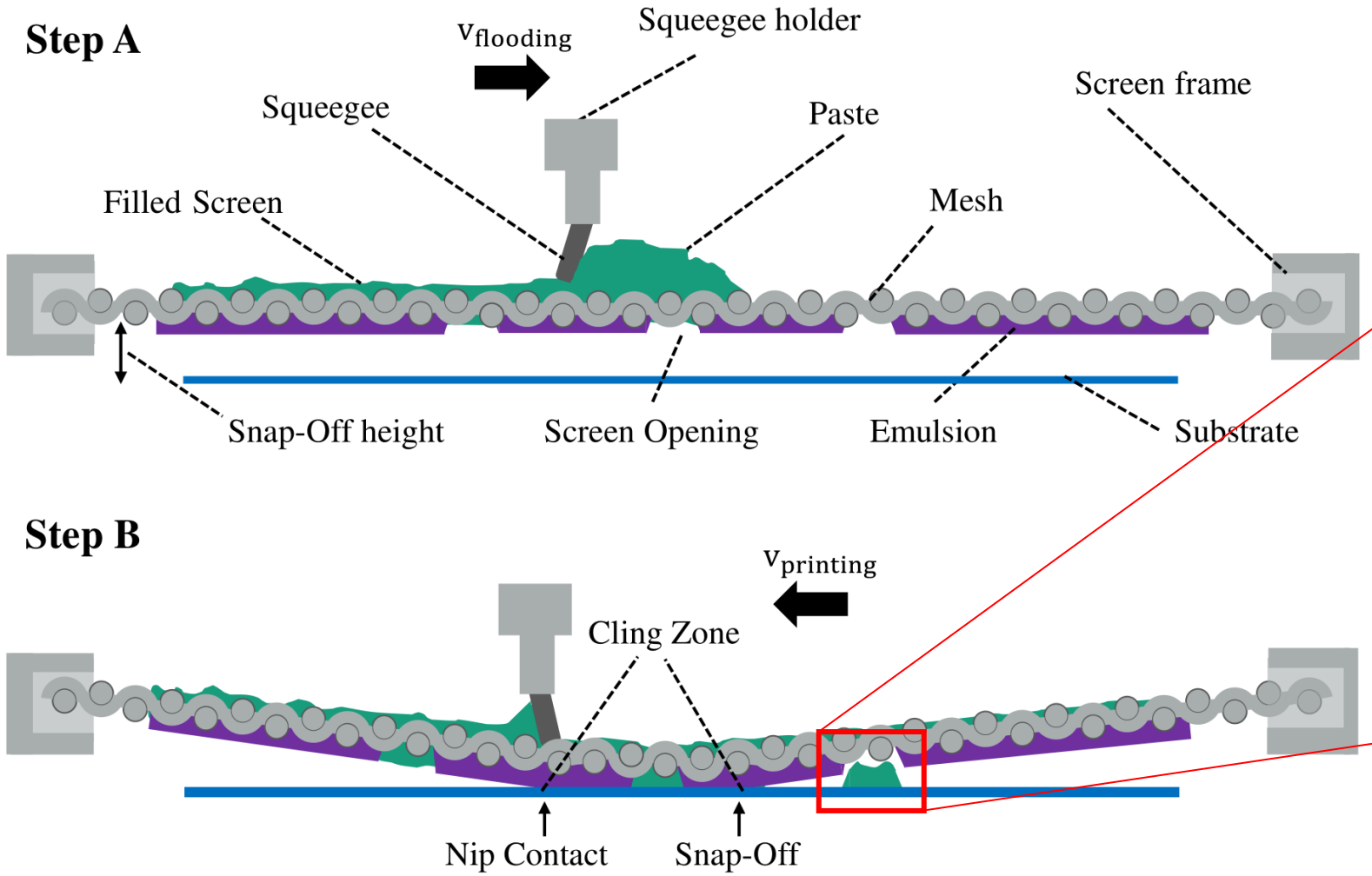
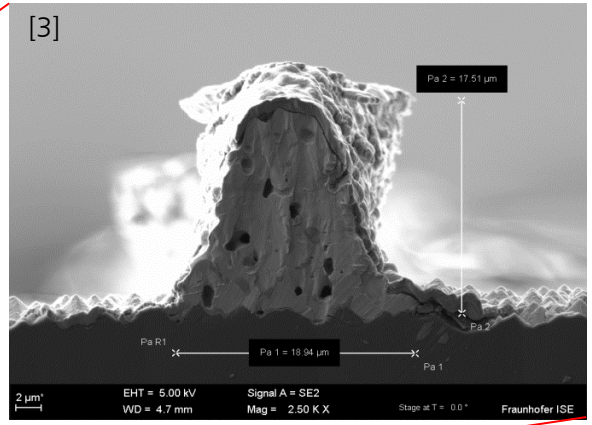
Metallization via Flatbed Screen Printing

State of the Art: Over 95% Usage

[2]



[3]



[2] S. Tepner et al., Solar Energy Materials and Solar Cells, 2019, https://doi.org/10.1016/j.solmat.2019.109969

[3] S. Tepner et al., Progress in Photovoltaics, 2020, https://doi.org/10.1002/pip.3313

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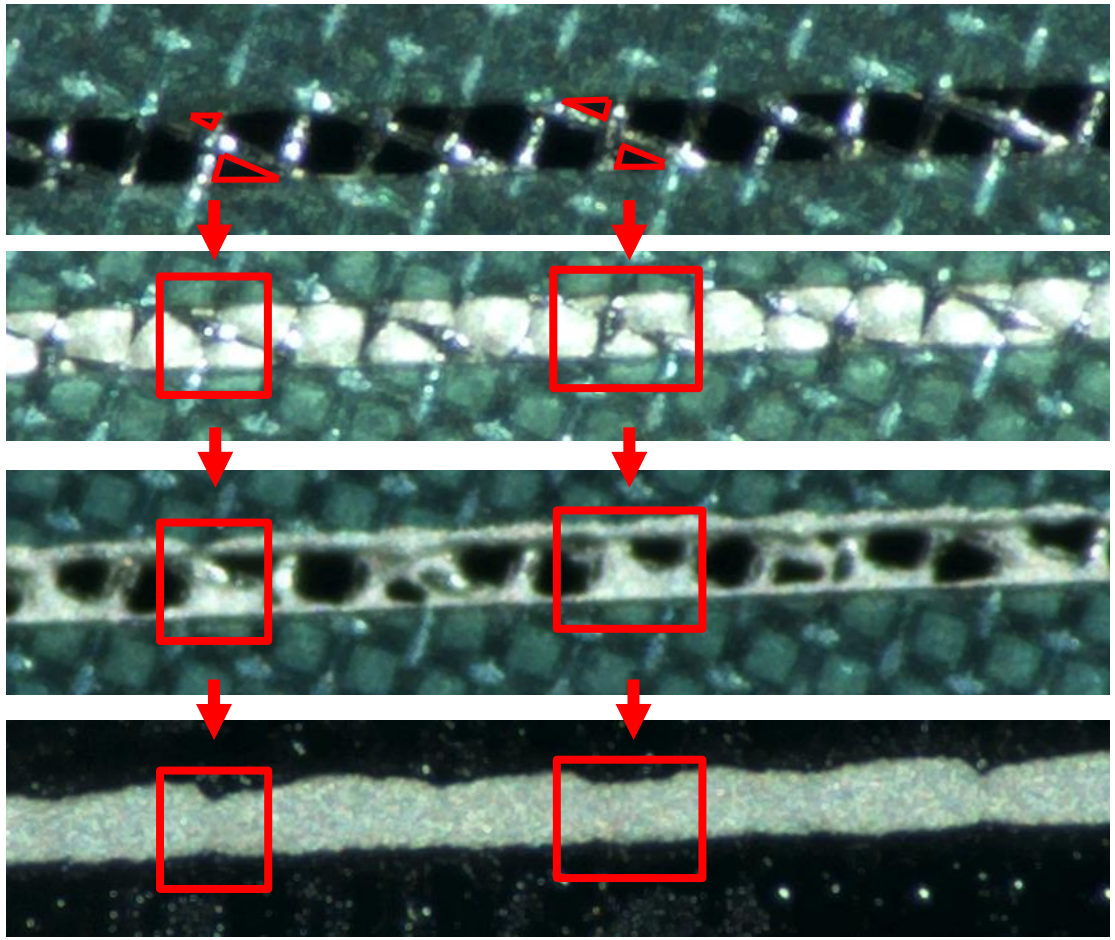
Metallization via Flatbed Screen Printing

Challenges in Screen Printing: Suboptimal Silver Usage and Mesh Marks



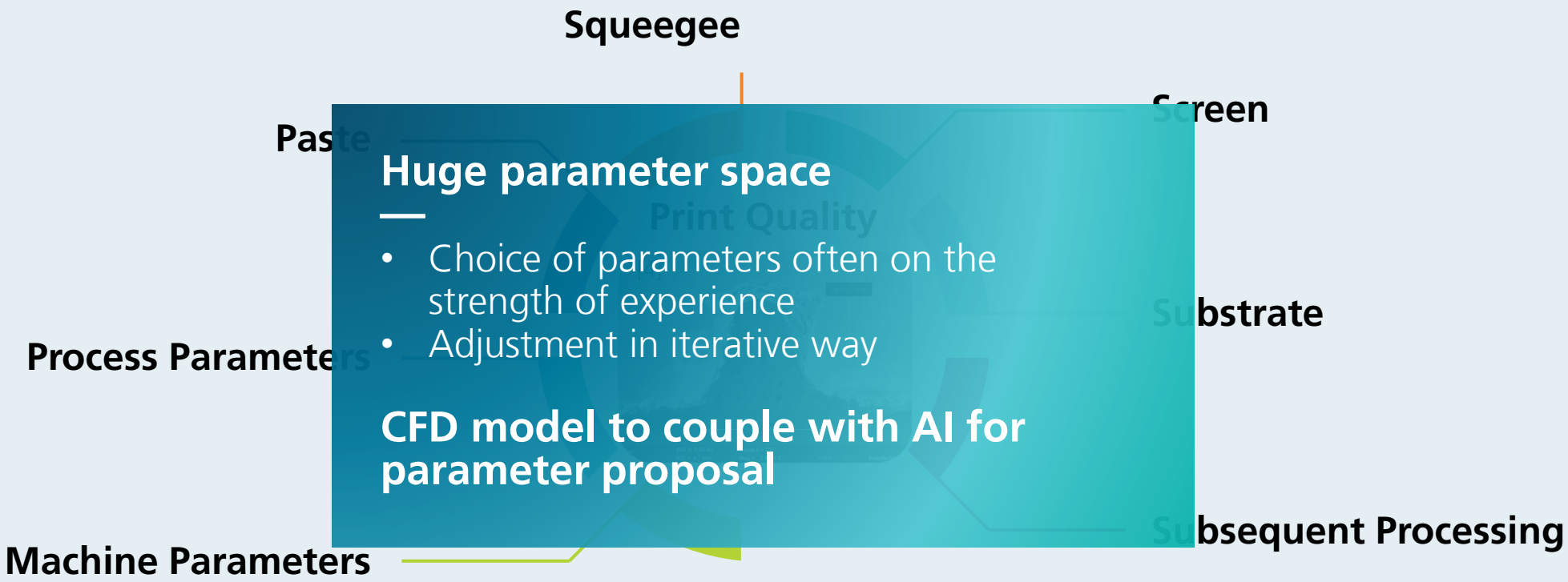
1. Pristine Screen
2. Flooded Screen
3. Screen after Snap-Off
4. Print result

- Inhomogeneous print result
- Mesh marks
- Interrupted fingers
- Residue of paste
- Clogging

Metallization via Flatbed Screen Printing

Influences on the Print Result

CFD = Computational Fluid Dynamics

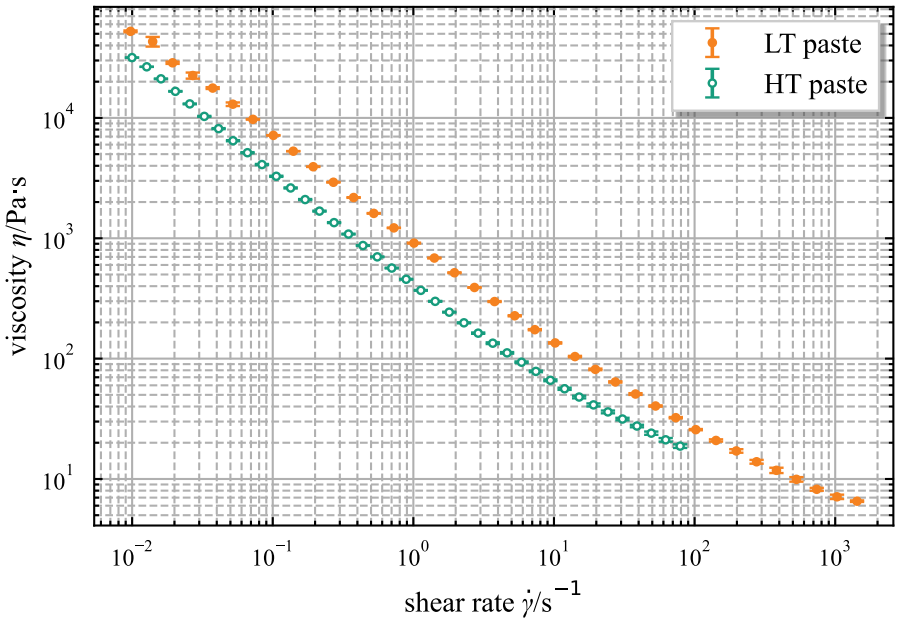


[4] S. Tepner et al., Progress in Photovoltaics, 2020, https://doi.org/10.1002/pip.3313

[5] Dissertation P. Hahne, 2000

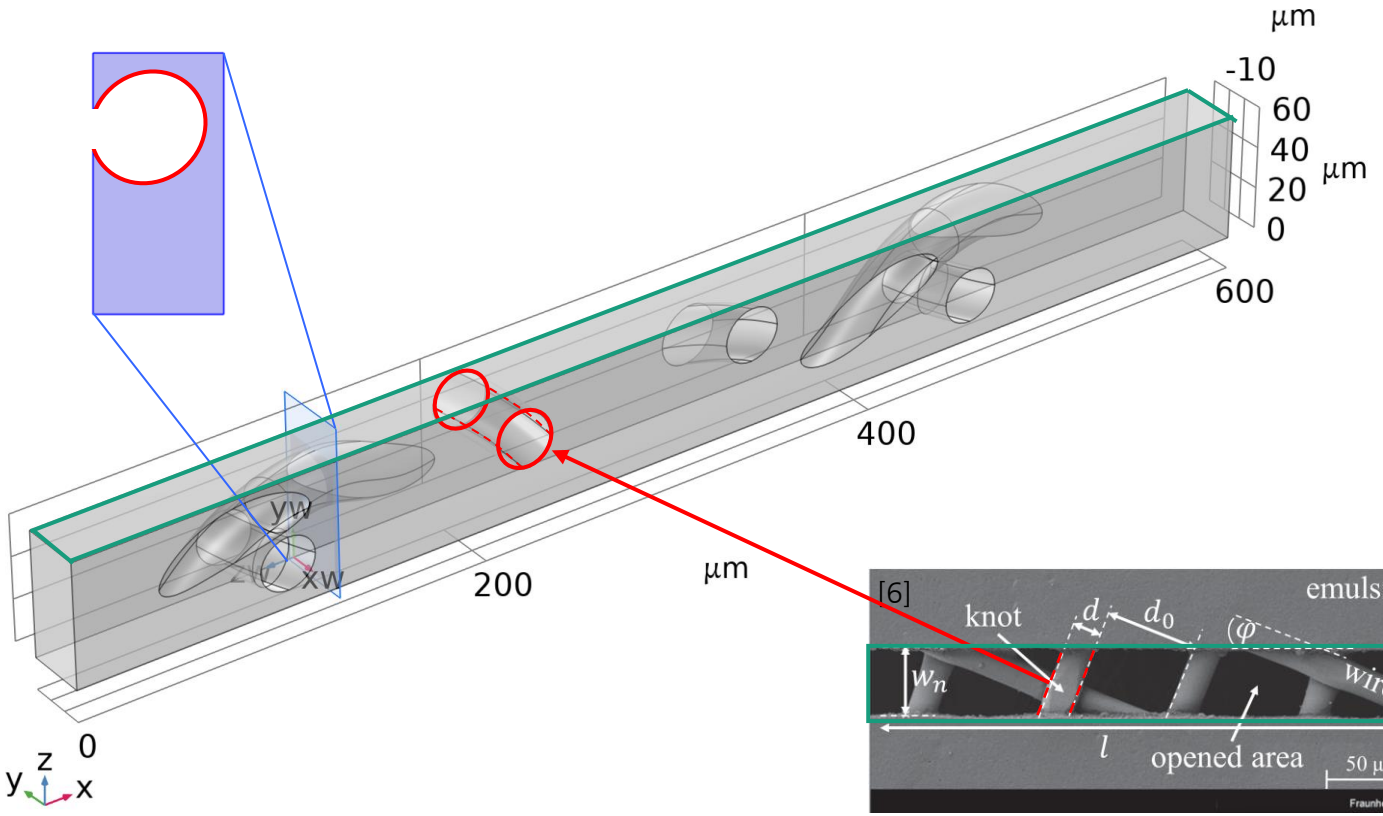
CFD-Simulation for Screen Printing

Setup of the Model



Rheological paste characterization

- Shear-thinning fluid
- Assume homogeneous fluid



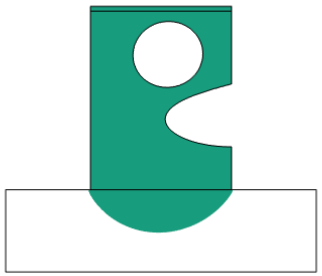
Printing channel

[6] L. Ney et al., AIP Conference Proceedings, 2019, https://doi.org/10.1063/1.5125871

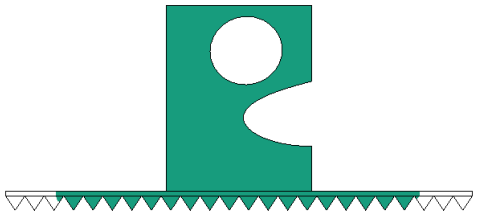
CFD-Simulation of the Screen-Printing Process

Basics: Steps

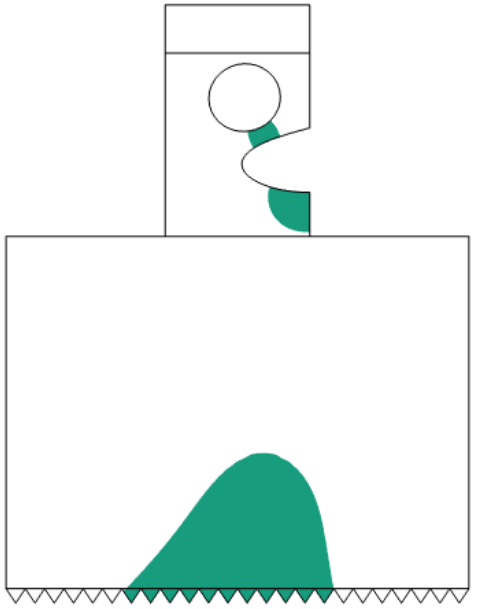
Flooding



Nip-Contact



Snap-Off

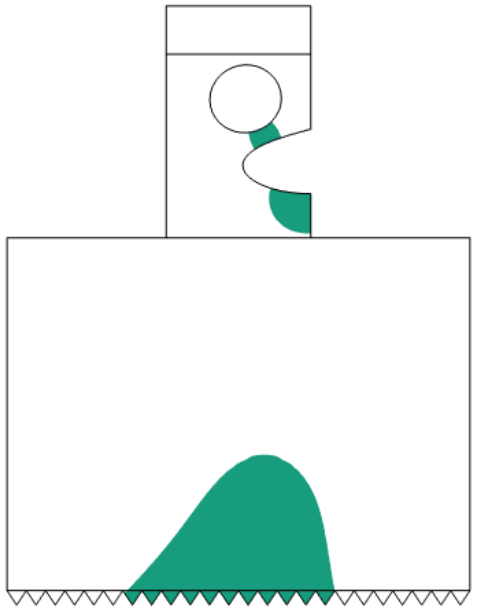


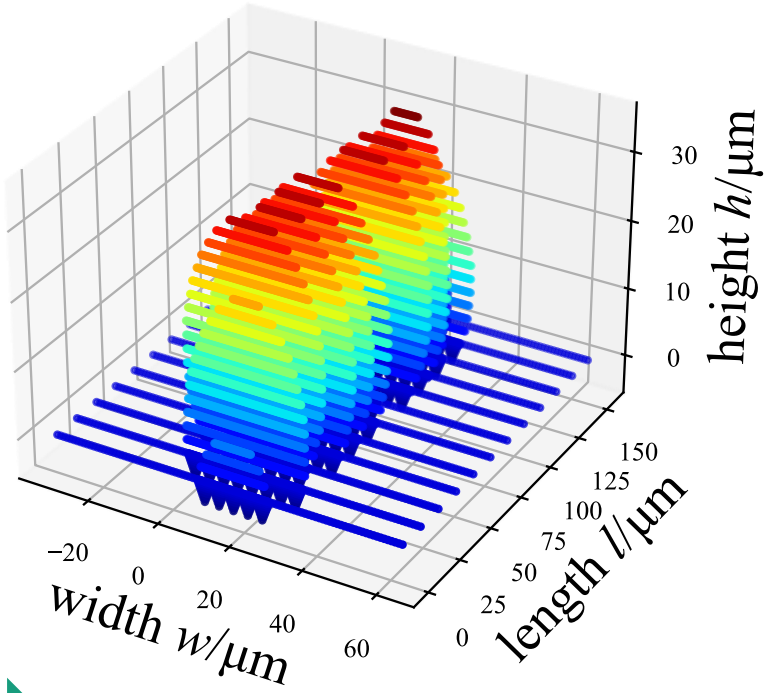
Step A (Flooding)

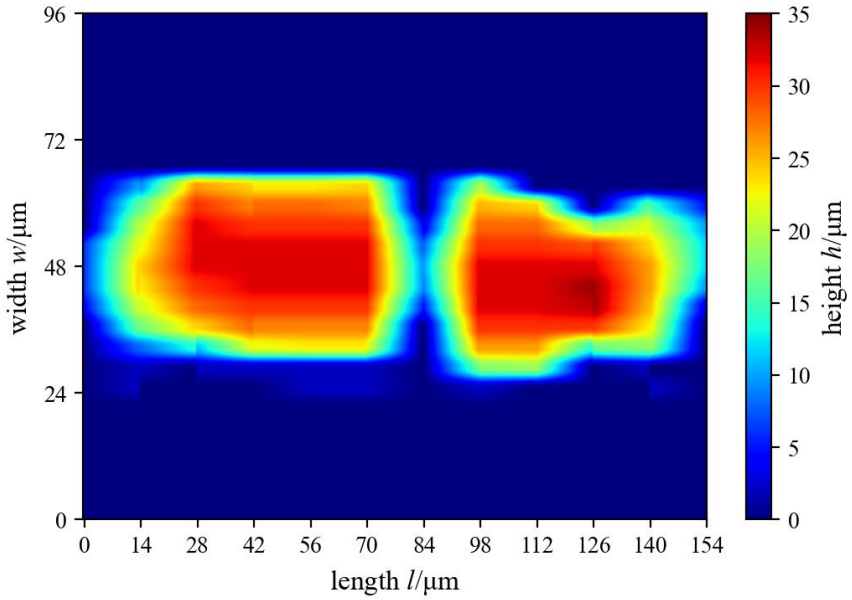
Step B (Printing)

Prediction of the Contact Finger

Interpolating the Cross-sections







Cross-Sections → Defined distance → **Alignment** → Linear interploation → **Height Map**

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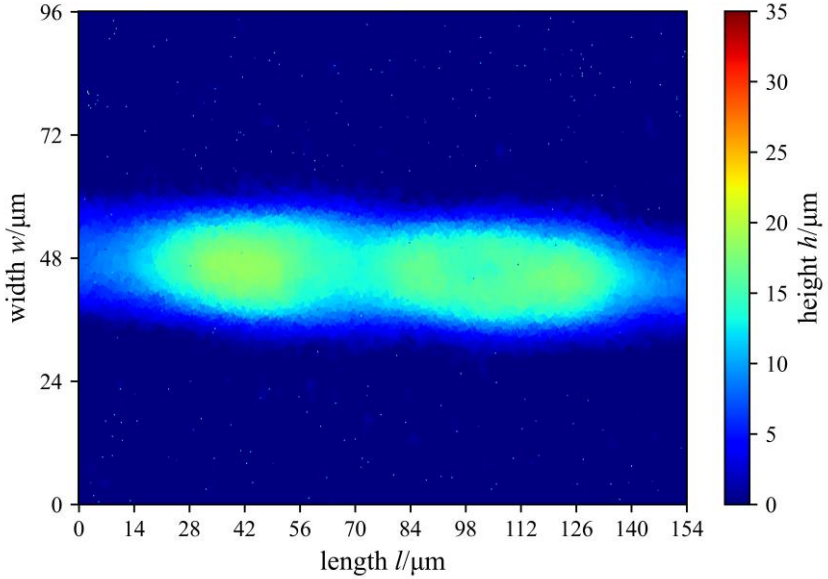
Simulation Results and Comparison to CLSM

Paste 1 with Fine Mesh and 30 µm Channel

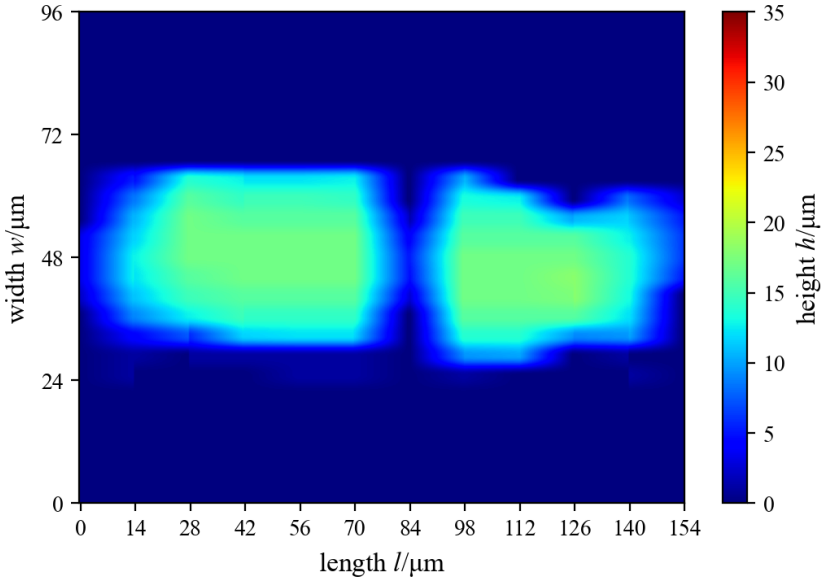
- Prediction of narrowings
- Regions of maximum finger height

	CLSM	Sim
Avg. height/µm	(15 ± 3)	(16 ± 5)
Avg. width/µm	(29 ± 3)	(32 ± 8)

CLSM:



SIM:



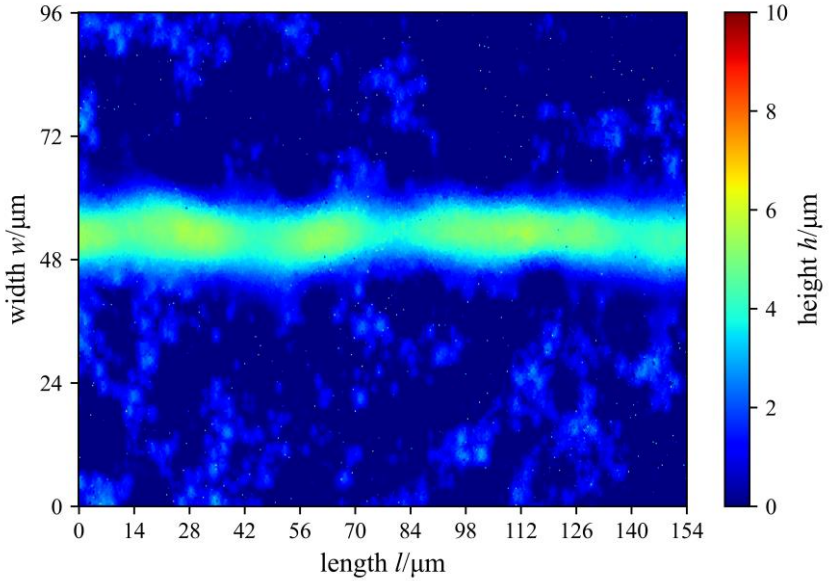
Simulation Results and Comparison to CLSM

Paste 2 with Fine Mesh and 15 µm Channel

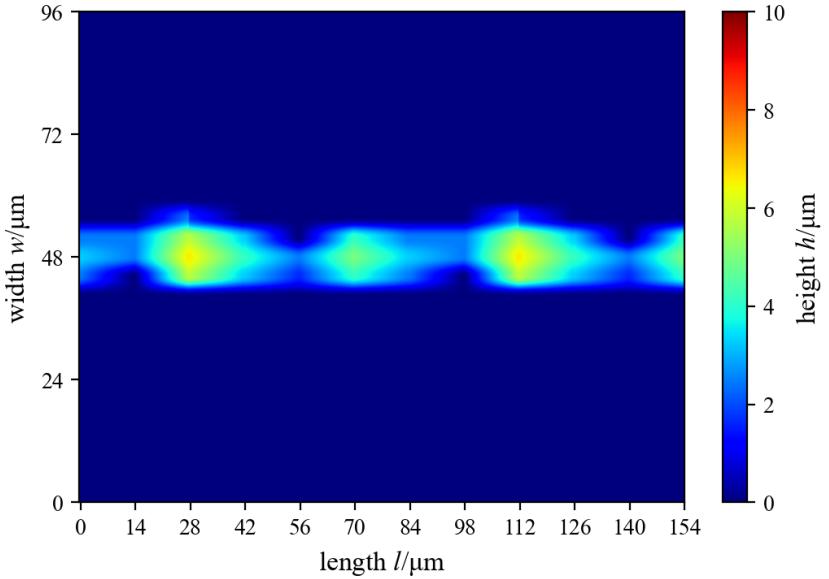
- Prediction of narrowings
- Regions of maximum finger height

	CLSM	Sim
Avg. height/µm	(4.9 ± 0.5)	(6.6 ± 1.3)
Avg. width/µm	(14.5 ± 1.9)	(14.2 ± 1.9)

CLSM:



SIM:



Simulation Results and Comparison to CLSM

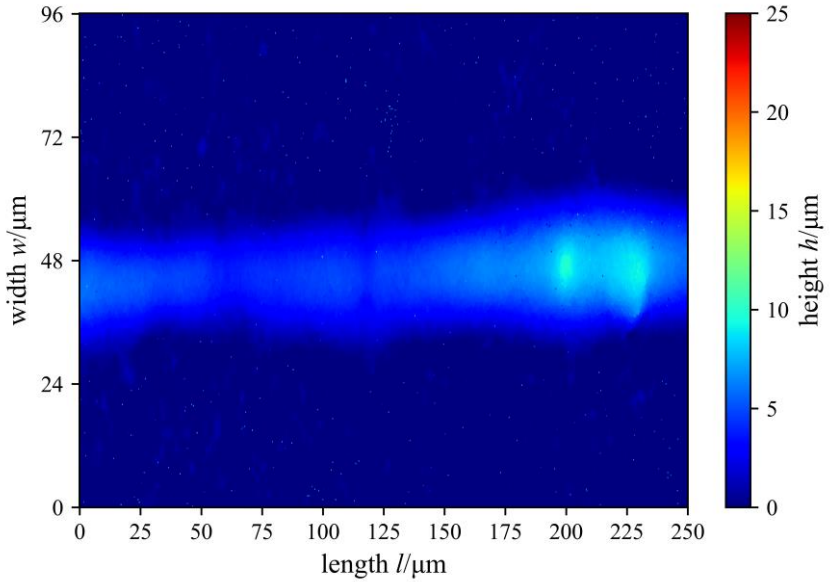
Paste 2 with Coarse Mesh and 30 µm Channel

- Prediction of narrowings
- Regions of maximum finger height

	CLSM	Sim
Avg. height/µm	(7.8 ± 1.7)	(15 ± 10)
Avg. width/µm	(40 ± 3)	(33 ± 12)

- No interaction between two dimensional cross-sections
- No distribution of paste between cross sections
- Thicker wires lead to increased difference between cross sections

CLSM:



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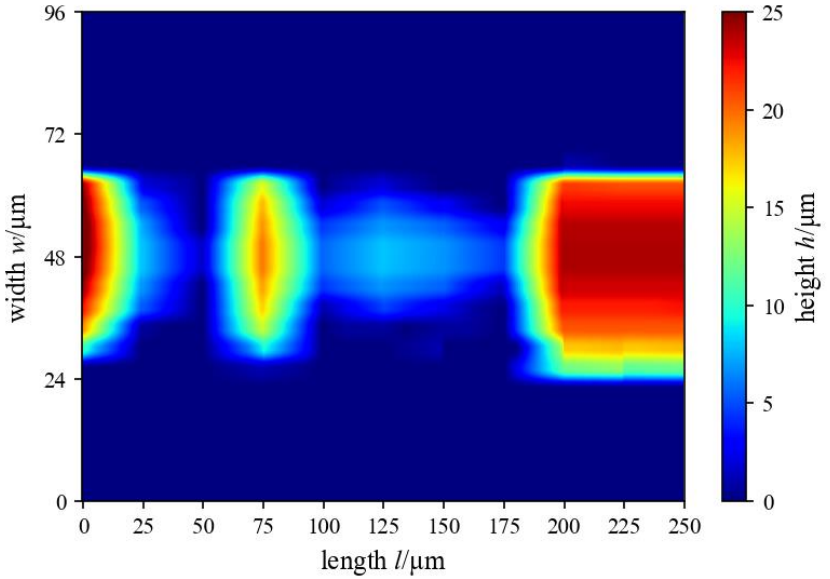

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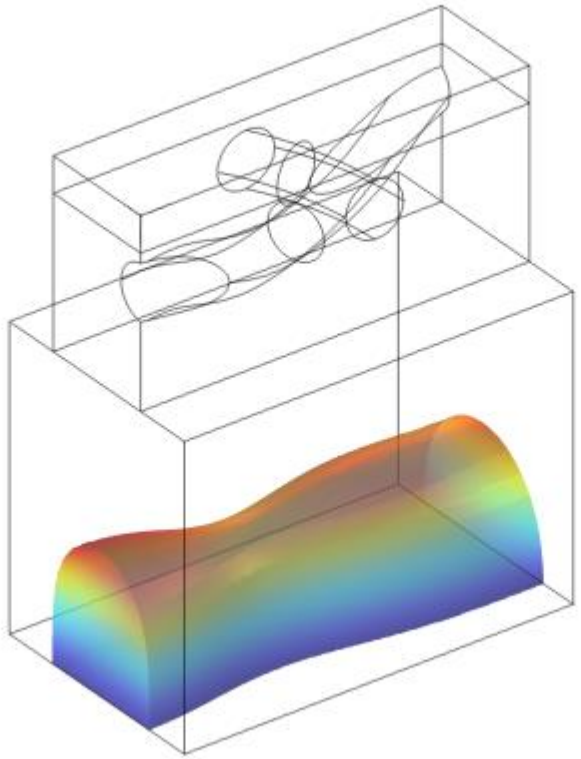
Potential Improvements

Outlook

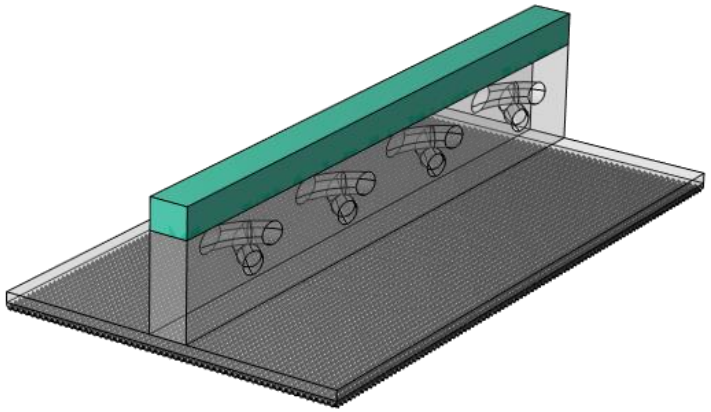
- Coupling the cross sections
  - Implemention of sources and sinks

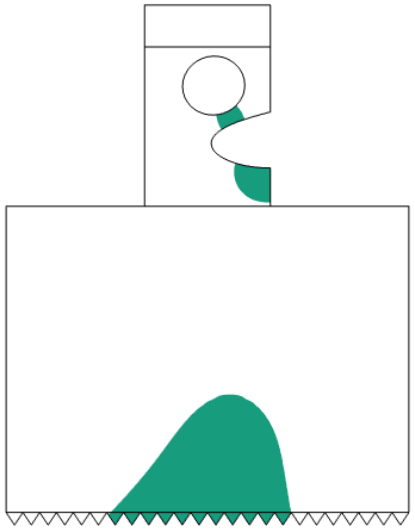
- 3D simulation
  - Reduced robustness
  - Low resolution
  - High calculation time
  - Complicate scaling

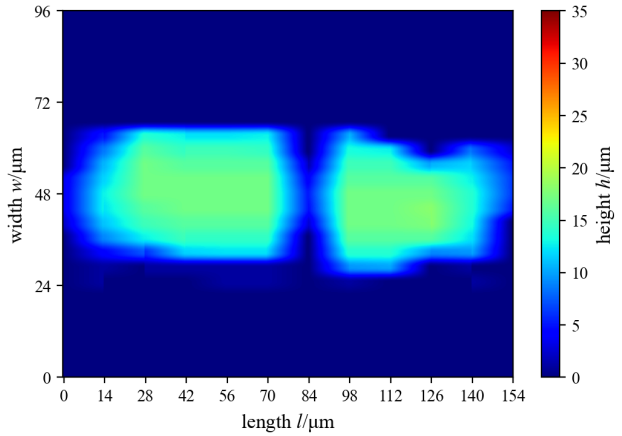


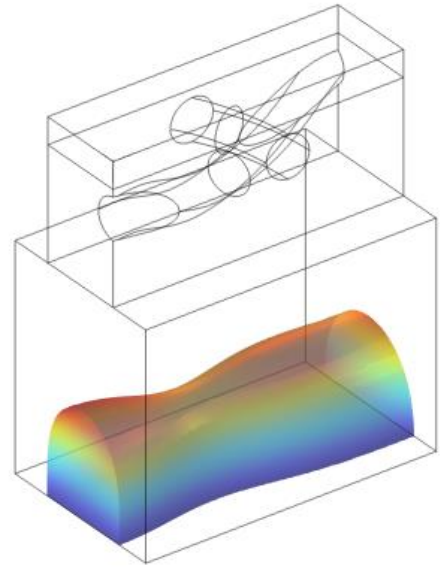
Summary

CFD-Simulation of the Screen-Printing Process









Basis of a CFD-Model
Automated generation of the geometry, allowing for automatical parameter variation

2D Cross-Sections
Modelling of the process in 3 simulation steps

Finger Prediction
Interpolation of the 2D cross sections

Basics of 3D-Model
Work in progress, potential for solving issues of 2D approach

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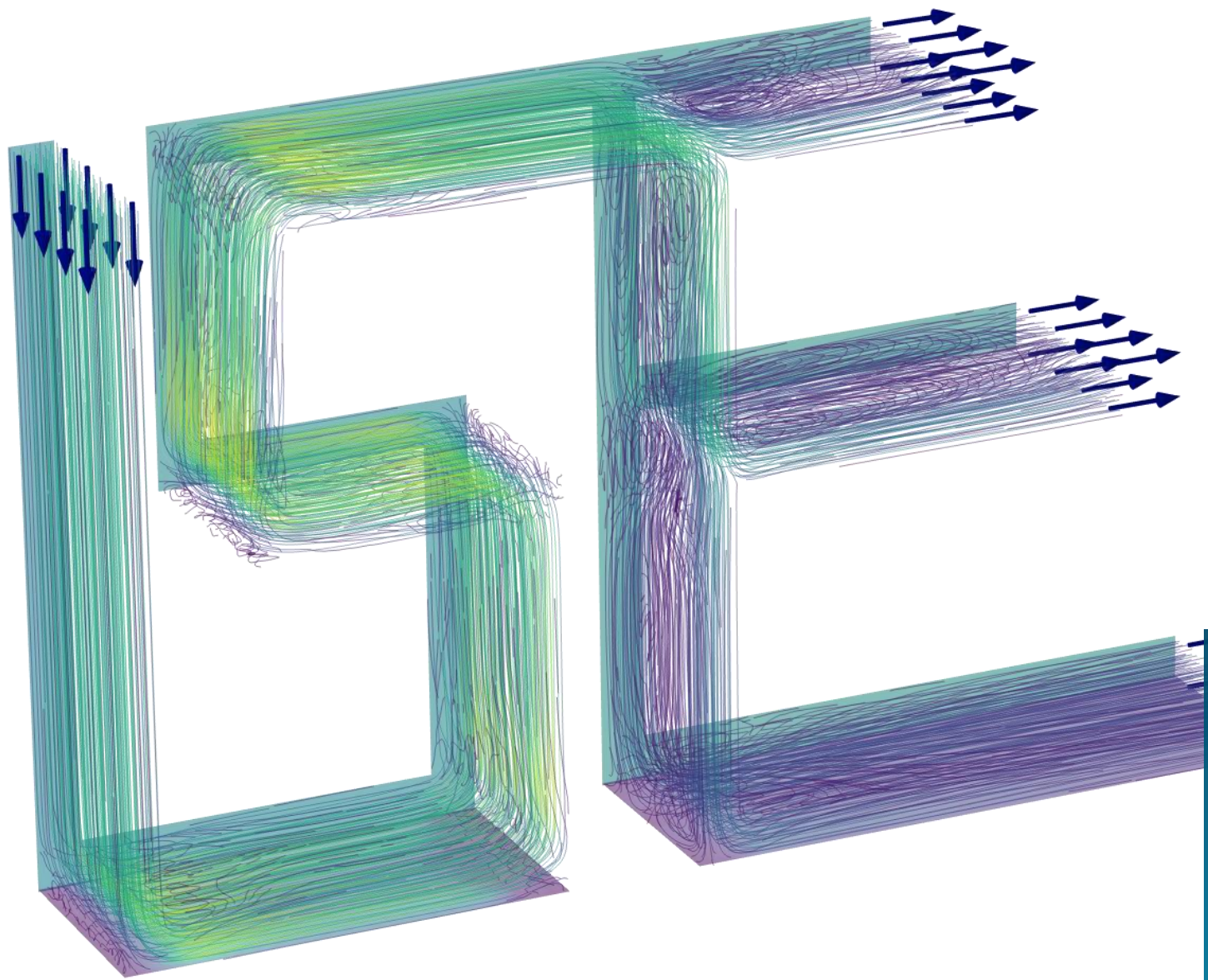

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