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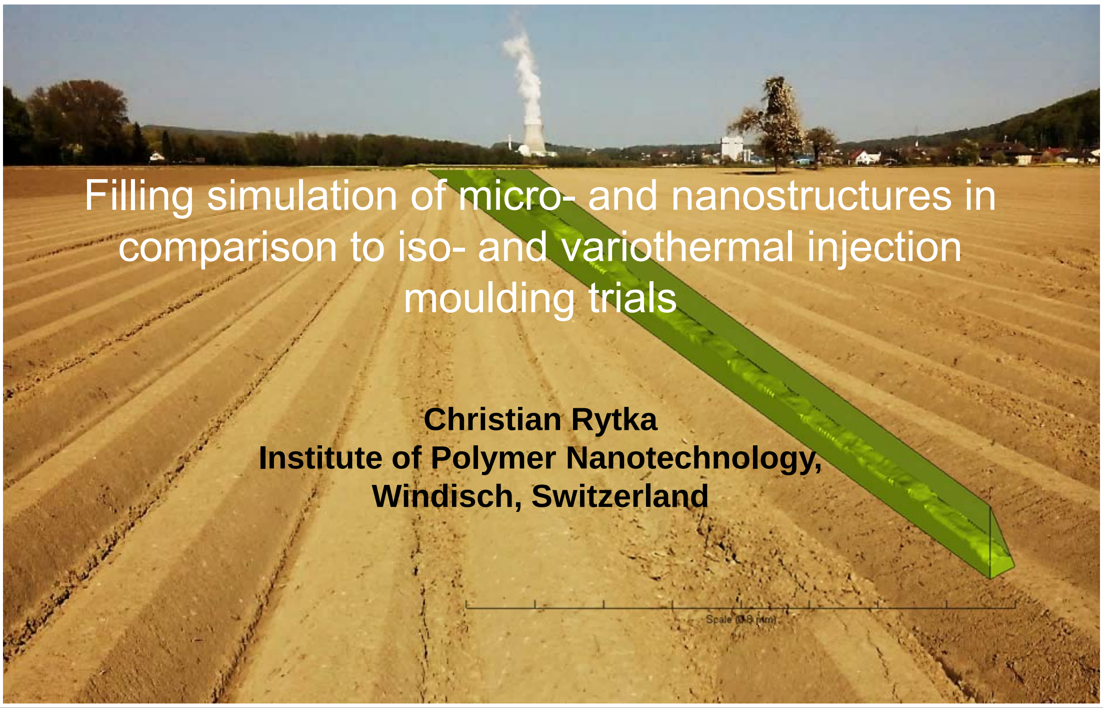

Filling simulation of micro- and nanostructures in comparison to iso- and variothermal injection moulding trials

Christian Rytka
Institute of Polymer Nanotechnology,
Windisch, Switzerland

Fachhochschule Nordwestschweiz
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Institute of Polymer Nanotechnology (INKA)

Joint Venture: University of Applied Sciences & Paul-Scherrer Institute (PSI)

FHNW - IKT & INKA

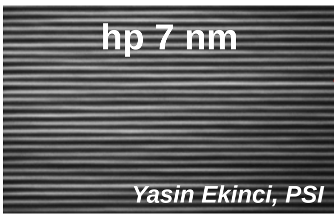
LMN - Laboratory for Micro- und Nanotechnology

Windisch

INKA

↔ 10 km

Villigen



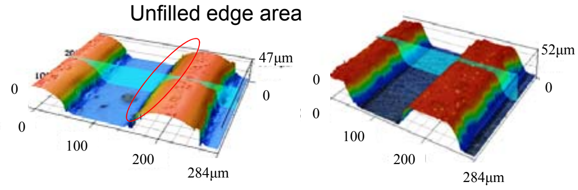
Applications and Challenges: Microfluidic Analysis Systems

courtesy of Bernd Müller for IMTEK & Hahn-Schickard

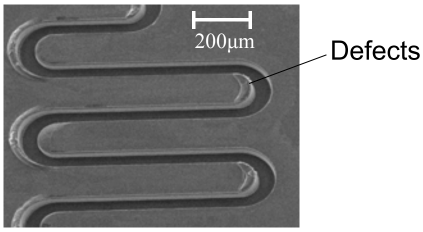
Lab-on-a-chip

Injection moulding issues:

1. Filling



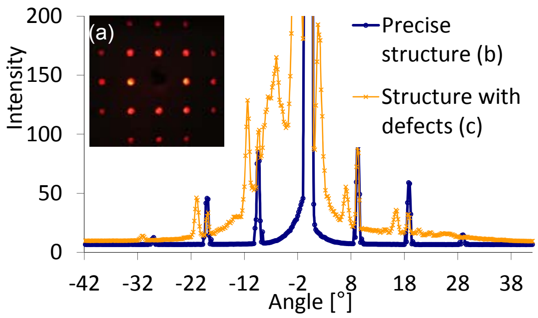
2. Demoulding

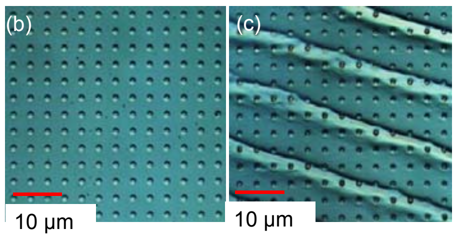


→ Strong impairment of functionaliy

Applications and Challenges: Optical applications

Optical diffraction pattern





inaccurate replication
→ irregular optical signals

Low replication quality reduces functionality of polymer surfaces

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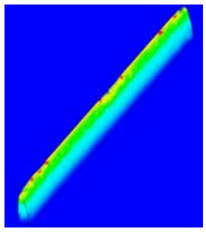
Motivation for Simulation

- **Fast prediction of filling behaviour**
  → Replication Ratio RR Master / Replica
- **Differences in materials**
  → no-flow temperature, viscosity
- **Different structure designs**
  → Width, height, aspect-ratio
- **Influence of processing parameters**
  → Mould temperature, injection speed, holding pressure…



Better understanding of the filling process in general!

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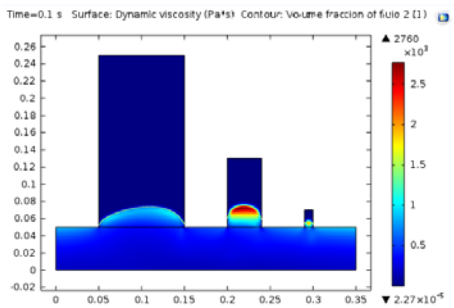
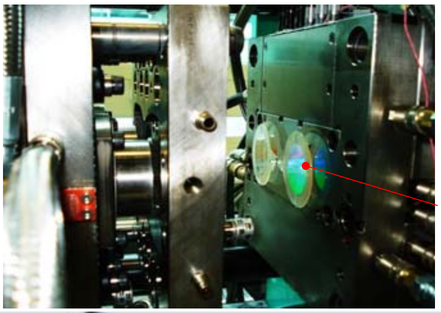
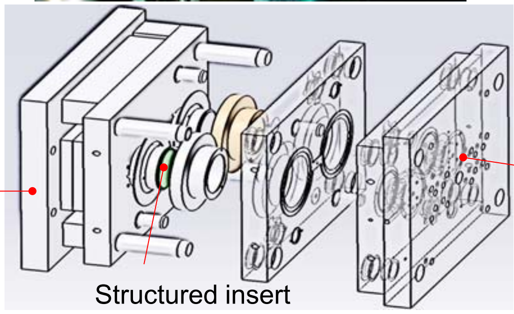
Content



1. **Introduction: Applications**
2. **Motivation for simulation**
3. **Multiscale model idea**
4. **Correlation of simulation with injection moulding trials**
5. **Prerequisites for precise simulation**
6. **Conclusions and Outlook**

Injection Mould

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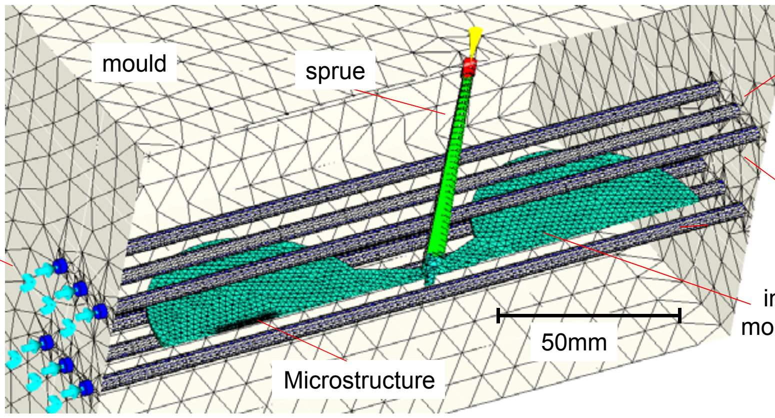
Moldflow Simulations: Analysis Sequences

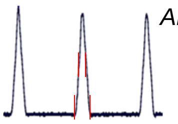
1. **Filling:** Most important sequence
2. **Packing:** Influence of holding pressure
3. **Cooling:** Cooling circuit
4. **Warping:** Important on macro scale

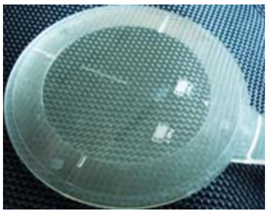


Simplification: Filling and Packing → Reduction of calculation time

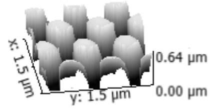
Model Approach

Laser-machined brass
w_m =22µm *h=123µm*
AR → 6

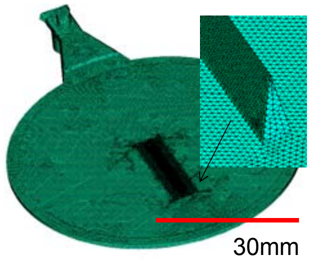




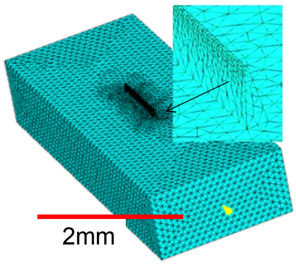
Lithographie Nickel
D=300nm; h= 600nm
AR → 2



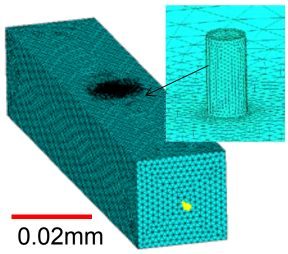
Macro; V = 7.6cm³



Micro; V=0.01cm³



Nano; V = 4*10⁻⁸ cm³

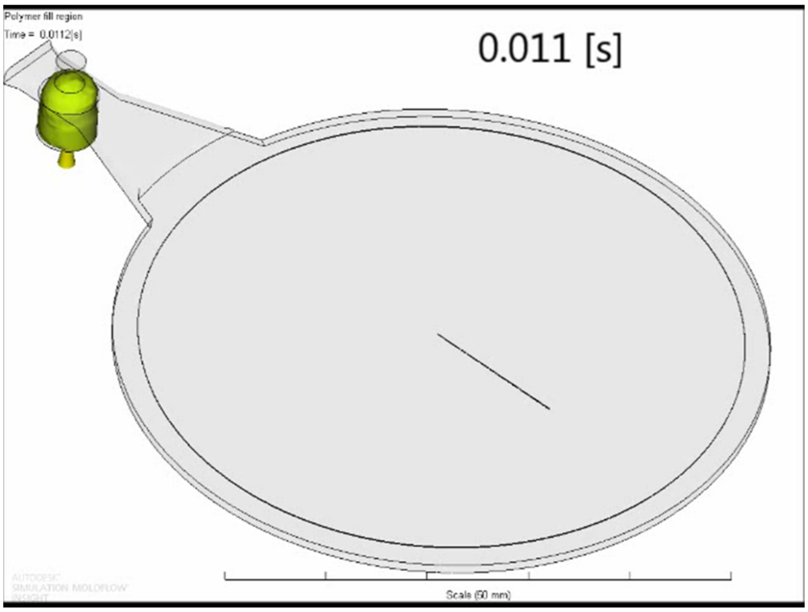


8.3 Mio elements → 400h

0.1 Mio elements → 2h

0.3 Mio elements → 4h

3D Simulation: V-Microgroove; PMMA T_{mould} = 115°C



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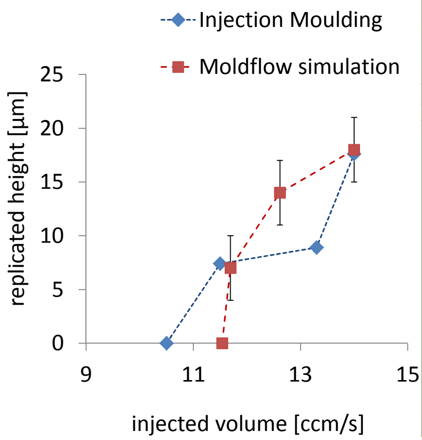
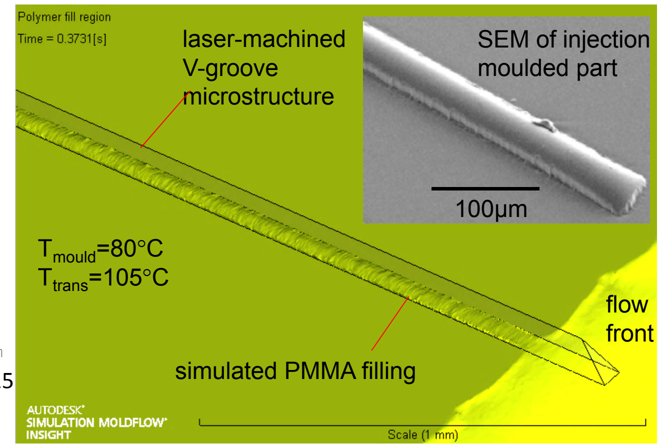
Short-Shots: PMMA, 15cm³/s





Good correlation of short-shots with simulation

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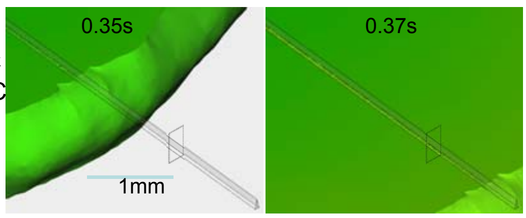
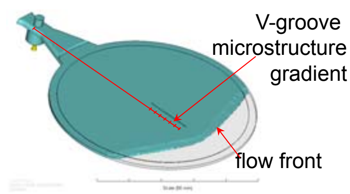
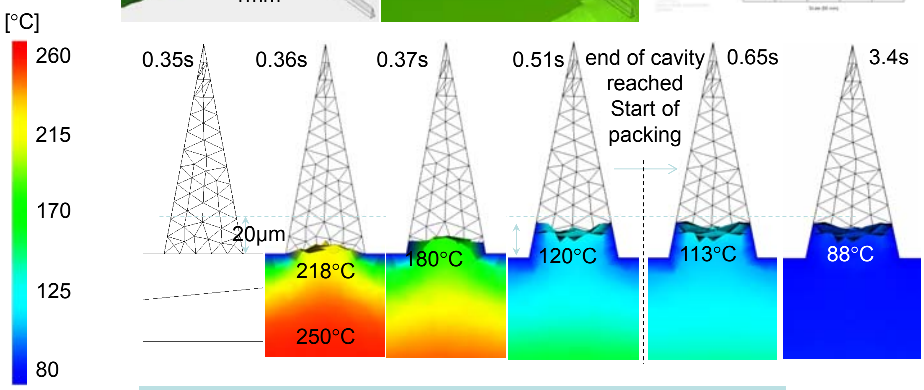
Moldflow Simulation, PMMA, 15cm³/s

T_{mould}=80°C
T_{trans}=105°C







If T_{mould} << T_{trans} → filling takes place before packing

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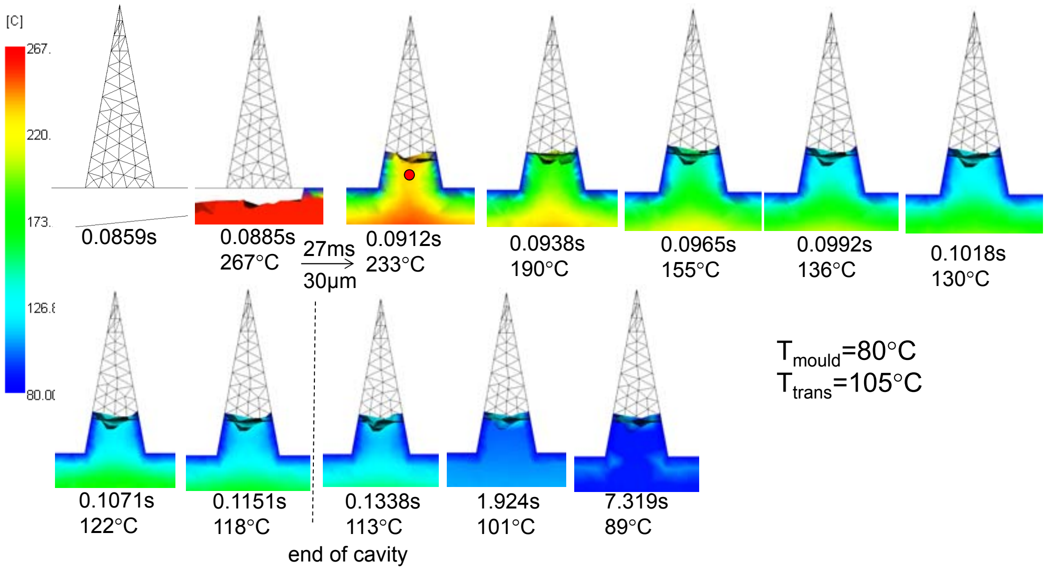
Moldflow Simulation, PMMA, 60cm³/s



T_{mould}=80°C
T_{trans}=105°C

Much faster filling and cooling compared to v_{inj}=15cm³/s

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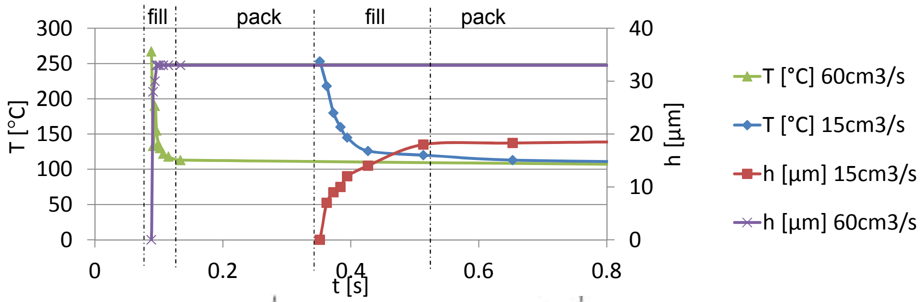
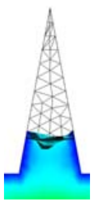
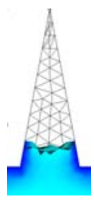
Moldflow Simulation PMMA - Comparison 15cm³/s vs. 60cm³/s



v_{inj}=60cm³/s
Δt=8ms
Δh=33µm



v_{inj}=15cm³/s
Δt=162ms
Δh=18µm



High injection speed:
very fast filling with higher melt temperature, but faster cooling

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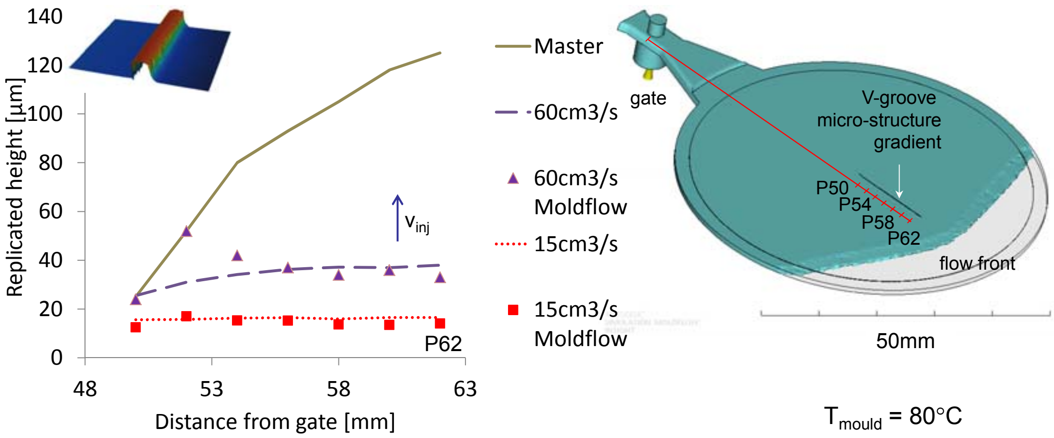
Comparison Simulation with Experiments



- Improved replication with higher injection speed
- Good correlation with Moldflow simulation for different v_{inj}

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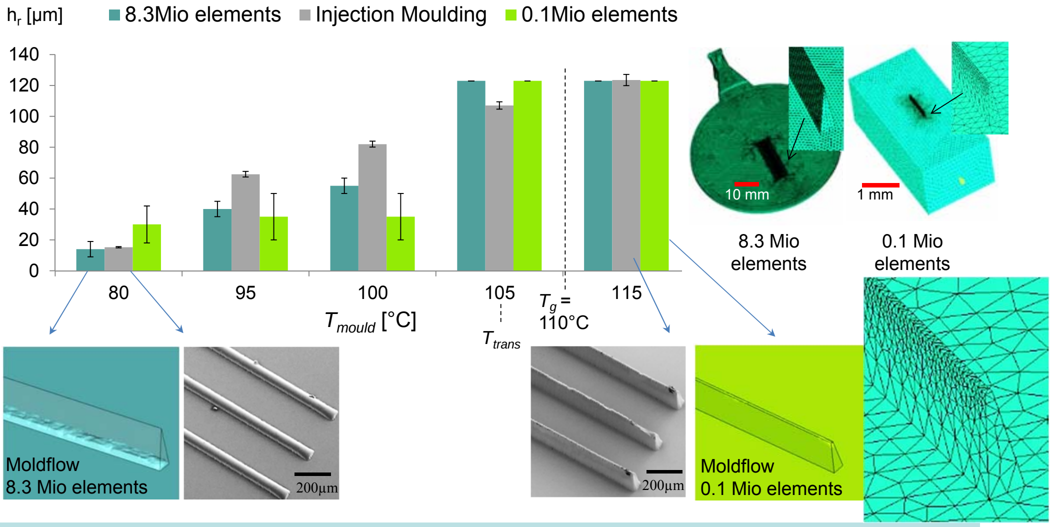
3D Simulation on Microscale: Influence of Mould Temperature

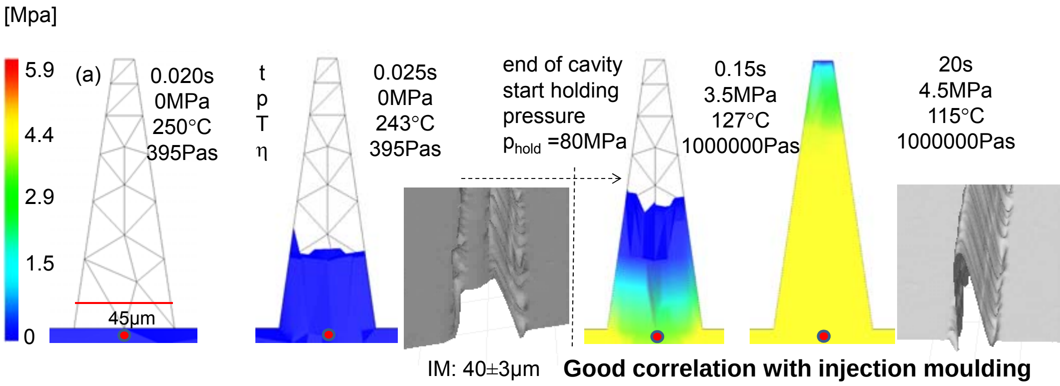
PMMA replica with v-groove microstructure



Good Correlation of simulation and experiments on microscale with 8.3 elements

Influence of holding pressure above Glass Transition Temperature

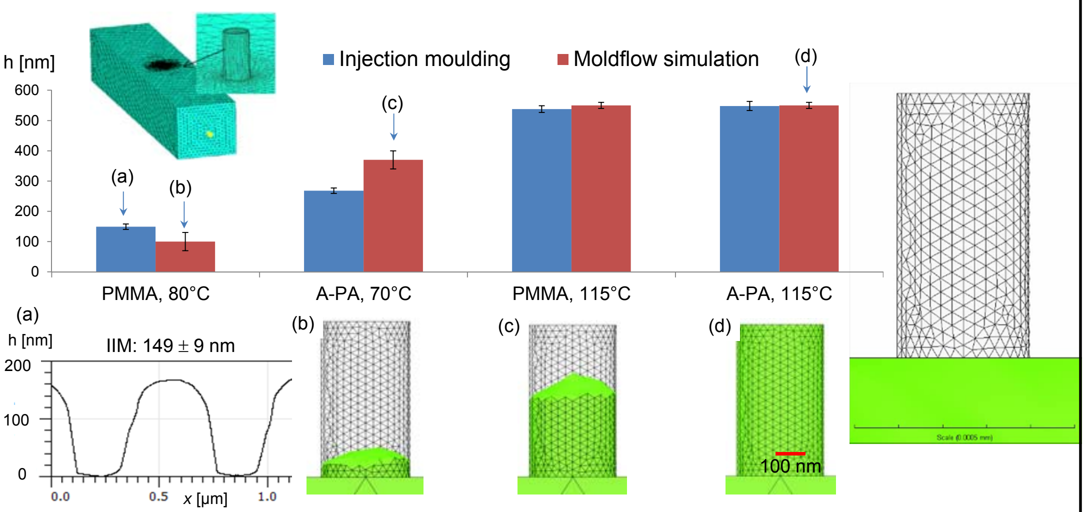
PMMA, T_{mould}=115°C, T_{trans}=105°C HTC=30000W/m²K



Good correlation with injection moulding

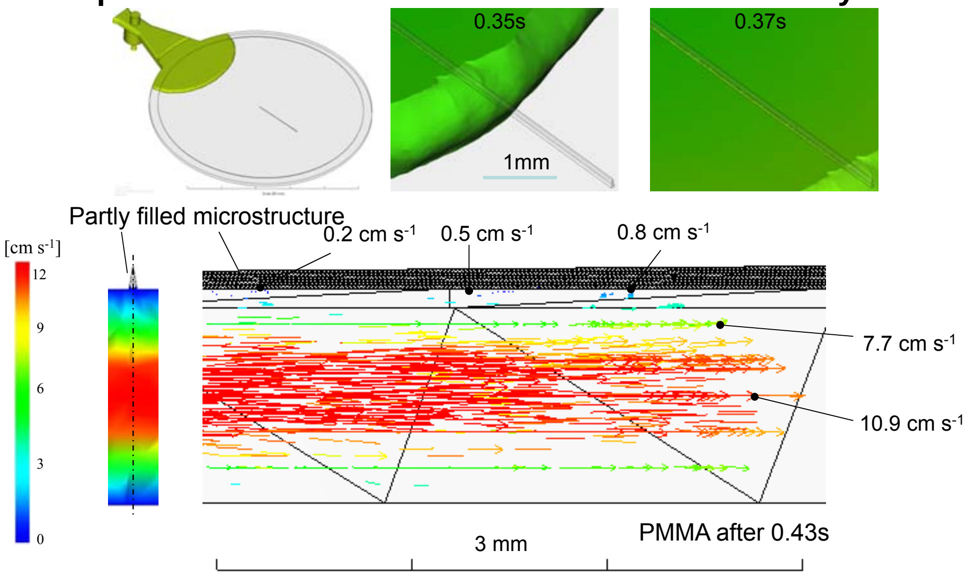
Packing stage: More important for variothermal process
→ cooling of polymer is delayed and material can be still pressed into the cavities

3D Simulation on Nanoscale: Influence of Mould Temperature



Good Correlation of simulation and experiments on nanoscale

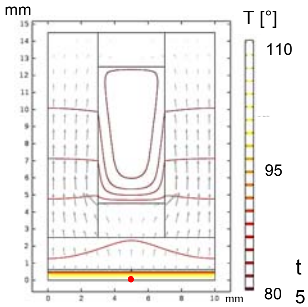
Prerequisites for Correct Simulation: Flow front velocity



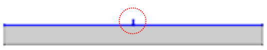
Transfer of correct flow front velocity

Prerequisites for Correct Simulation

Increase of heat transfer coefficient



Heat transfer with cooling channel

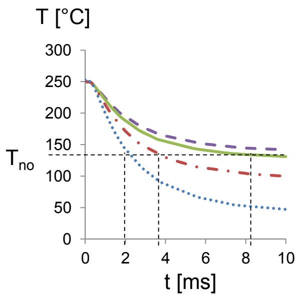


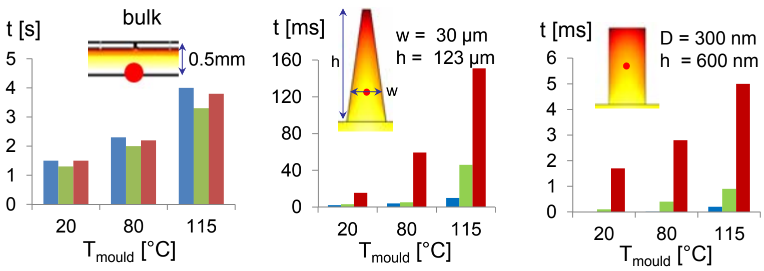
Convective heat flux:

$$q_0 = h_{tc} \cdot (T_{mould} - T)$$

h_{tc} = 30000 W m^{-2} K^{-1}

h_{tc} = 5000 W m^{-2} K^{-1}





Heat transfer: nano >> micro >> macro

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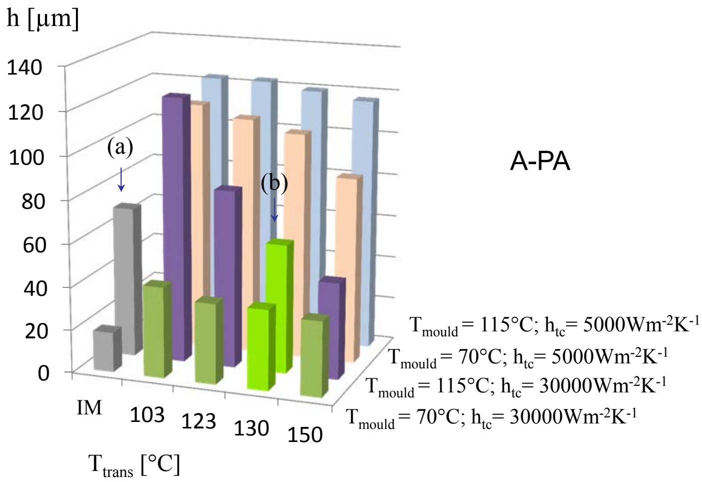
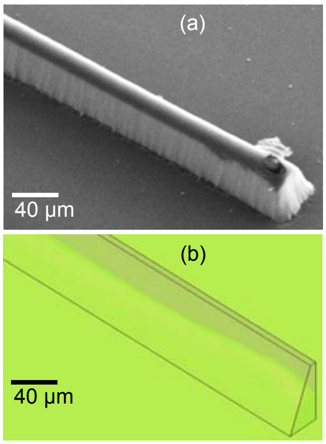
Prerequisites for Correct Simulation

Adaption of transition temperature to no-flow temperature





Correct T_{trans} is especially relevant for the holding pressure phase

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Summary / Conclusions

- Filling simulation of micro- and nanostructures: good correlation to experiments
  → For different materials and processing parameters, above and below T_g
  → Potential reduction of development time
- Most important for scaling:
  → Correct transfer of flow front velocity
  → Heat transfer coefficient and T_{no} have a significant influence on results
  → T_{trans} needs to be adapted to T_{no}
- T_{no} or T_{trans}
  → Especially influences variothermal replication in packing phase
  → Less effect on filling in isothermal process if $T_{mould} < T_{trans}$

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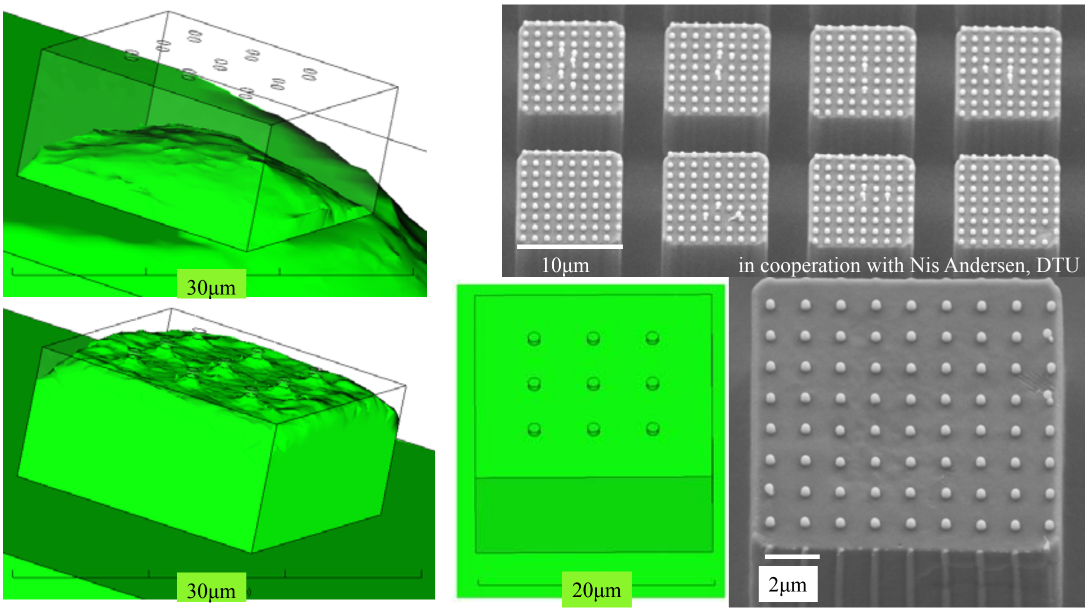
Simulation of Hierarchical Micro- and Nanostructures



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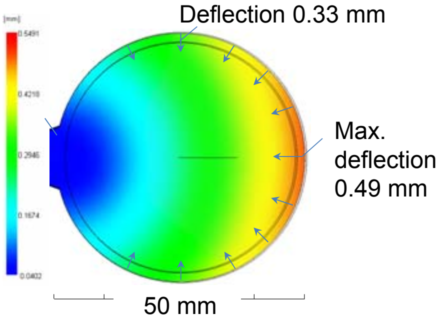
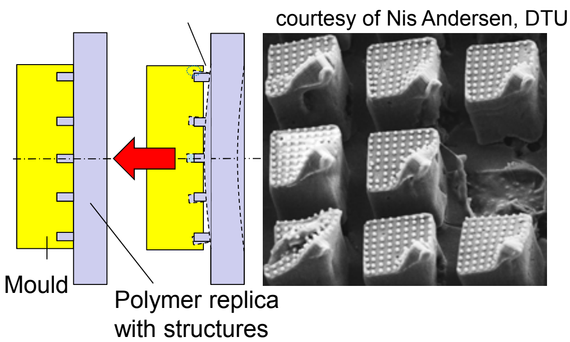
Outlook Demoulding



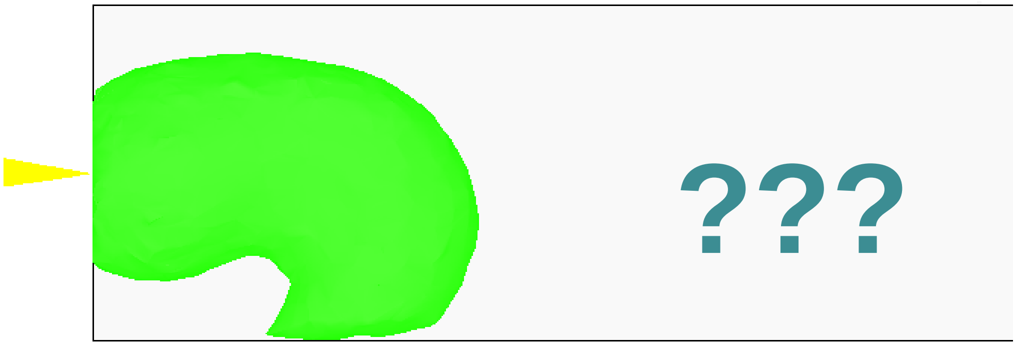


Stresses, Shrinkage?

Bending? Mould breathing?

Research ongoing

Thank you for your attention!



Injection mouldings trials published in:
Rytka C., Kristiansen P.M. , Neyer A., 2015
Iso- and variothermal injection compression moulding of polymer micro- and nanostructures for optical and medical applications, ***J. Micromech. Microeng.*** 25, 065008

Topic simulation published in:
Rytka C., Lungershausen J., Kristiansen P. M., Neyer A., 2016
3D filling simulation of micro- and nanostructures in comparison to injection moulding trials, ***J. Micromech. Microeng.*** 26, 065018