universität freiburg

2000 Glasgeschichte - Römische Nanotechnologie und Moderne Glasherstellung im 21. Jahrhundert

(The Glassomer Technology – Glass Shaping in the 21st century)

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Cluster of Excellence Living, Adaptive and Energy-autonomous Materials Systems (livMatS)

About the speaker

Prof. Dr.-Ing. habil. Bastian E. Rapp

Full Professor,
Laboratory of ProcessTechnology
Department of Microsystem Technology (IMTEK)
University of Freiburg

- 2005, mechanical engineering
  University of Karlsruhe
- 2008, PhD in Microfluidics and Biosensors
  University of Karlsruhe
- 2017, Habilitation on fluid mechanics and microfluidics
  Karlsruhe Institute of Technology (KIT)
- 2018, Full Professor Process Technology
  IMTEK, University of Freiburg
- 2018, Founding CEO and current CTO of Glassomer GmbH
- several industry/academic awards (selection):
  GMM, *Edison Award*, *Südwestmetallförderpreis*

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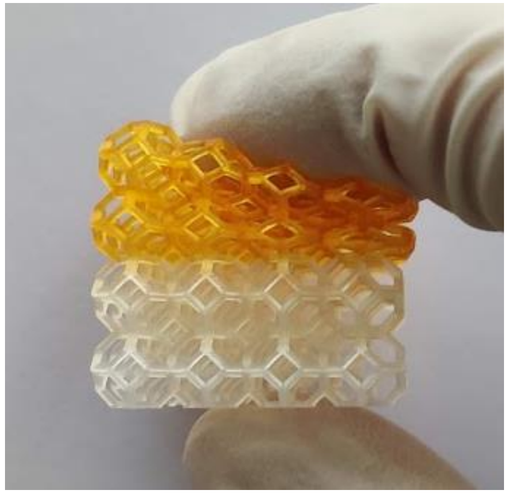
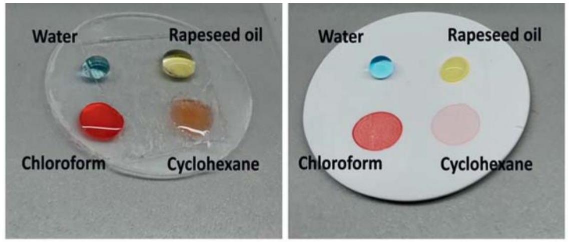
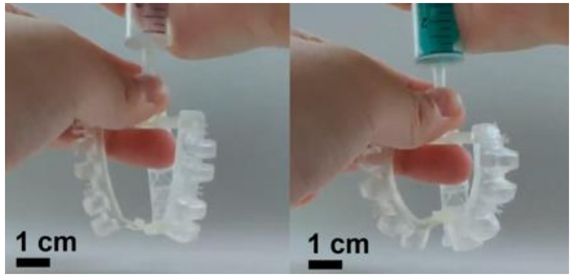
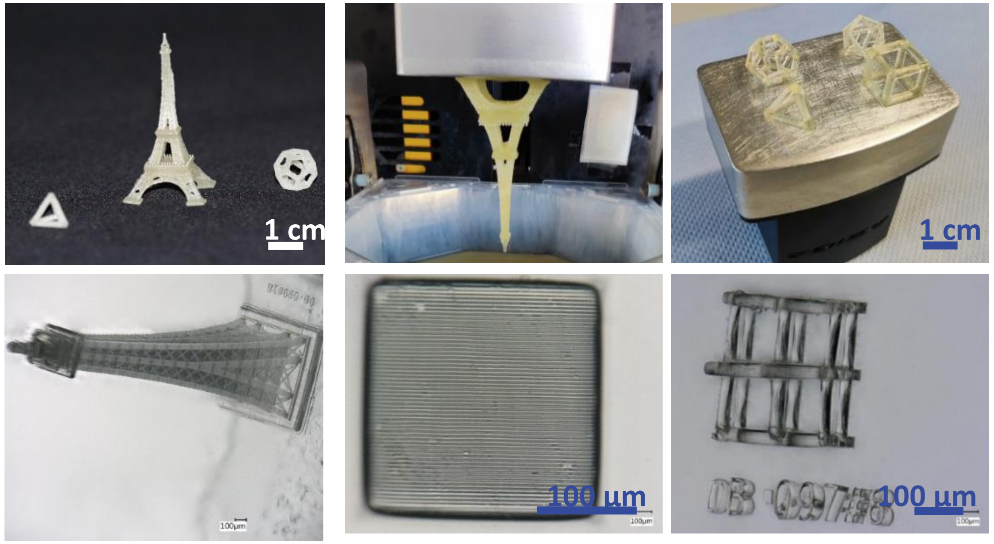
About my group, about myself









- interdisciplinary group: chemists, engineers, biologist and physicists
- focus on microsystem engineering, material design as well as process, instrumentation and application development
- several academic and industrial awards
- publishes in the most important international journals including *Advanced Materials*, *Lab-on-a-Chip*, *Angewandte Chemie* and *Nature* as well as *Science*

Glass – a fascinating material

Glass has shaped the history of mankind for more than

5000 years

But actually we often chose plastics over glass – why?

- × resource-limited (crude oil)
- × environmental hazard
- × expensive raw material
- × suboptimal material properties
- ✓ fast, cheap, scalable processing: injection molding, blow molding

Plastics

Glass

- ✓ made from sand
- ✓ can be ground back to sand
- ✓ two order of magnitude cheaper than plastics!
- ✓ excellent material properties
- × **expensive & difficult to process**

Glass Manufacturing Lacks Innovation

Melting / Glass blowing

☹ high temperatures (>1000 °C)

☹ dangerous

Grinding

☹ only simple geometries

☹ wastes material

Etching

☹ only simple geometries

☹ very dangerous chemicals (HF)

A lot has happened in the 21st century: **the polymer revolution**

- Injection molding et al. → fast and scalable
- 3D Printing → versatile and intricate

Conventional Glass making

Melting
requires
7.7 GJ/ton

Shaping
requires
5.6 GJ/ton

Refining
requires
3.7 GJ/ton

A new approach: The Glassomer Technology

Material Production

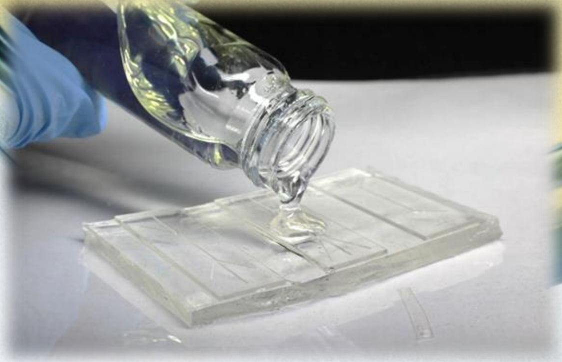
requires

2.9 GJ/ton

Shaping

requires

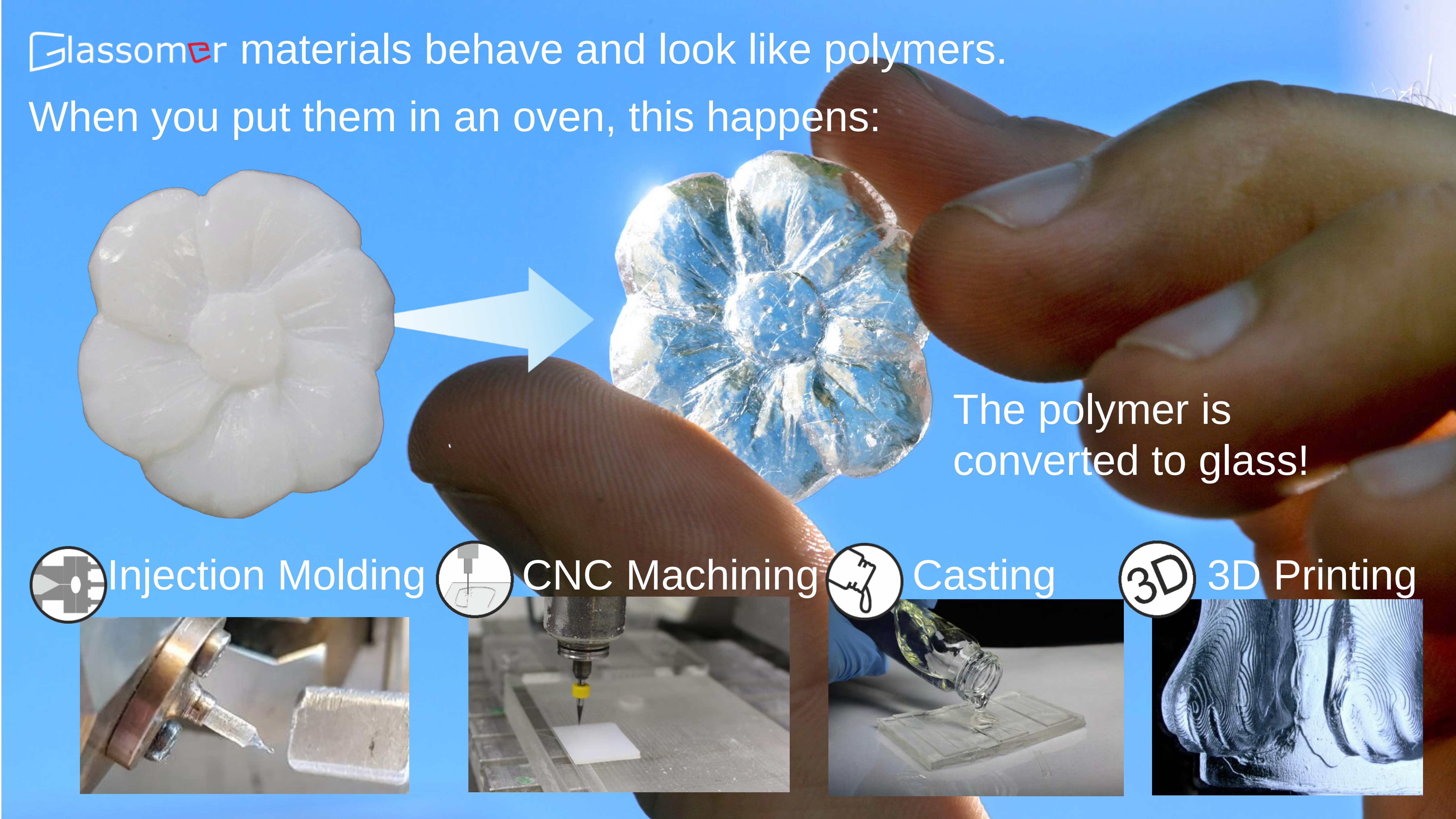
0.5 GJ/ton



Requires

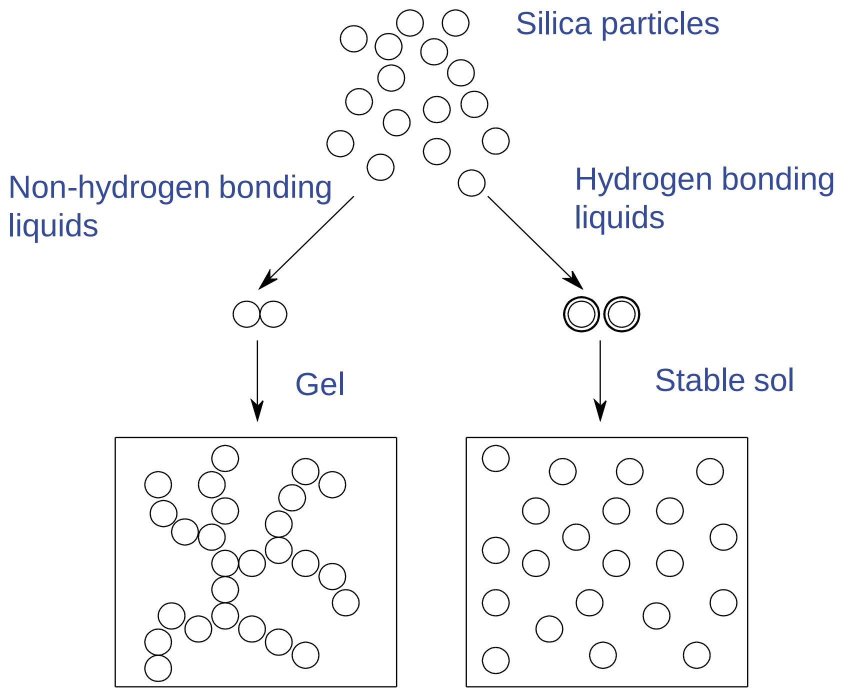
No Refining

→ 80 % less energy required
→ Almost unlimited designs
→ Highest purity

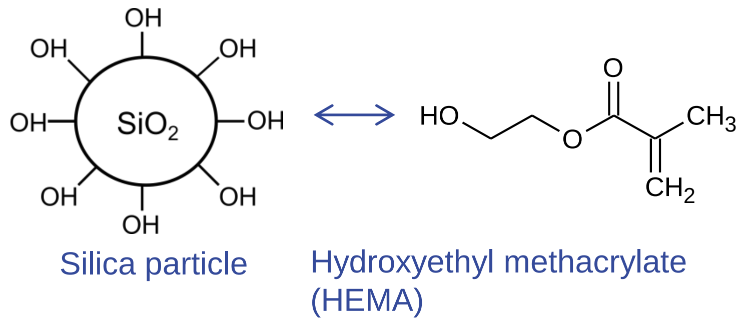

Glassomer materials behave and look like polymers.
When you put them in an oven, this happens:
The polymer is converted to glass!
Injection Molding
CNC Machining
Casting
3D Printing

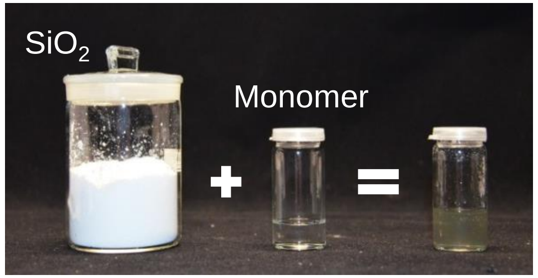
Glassomer® Technology: The silica in toothpaste

- Requirement for high quality glasses: high powder content
- Liquids, pastes or solid Glassomer® materials



Adapted from: Raghaven *et al.*, Langmuir **2000**

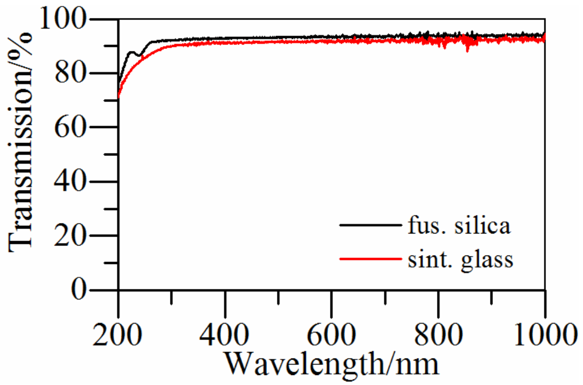




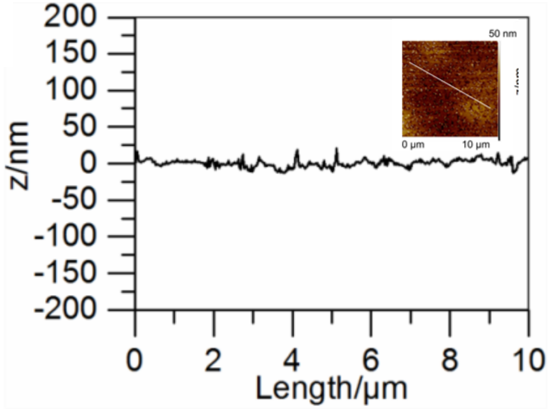
Kotz *et al.*, Adv Mat **2015**

Glassomer® glass = Fused Silica

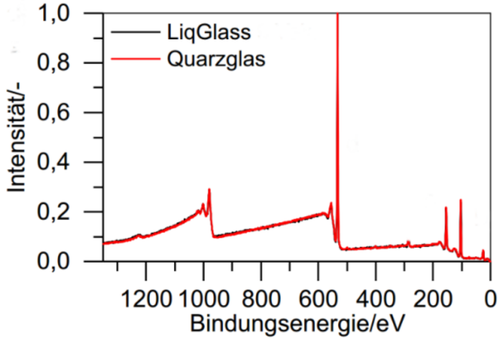
High Transparency



Low Surface Roughness



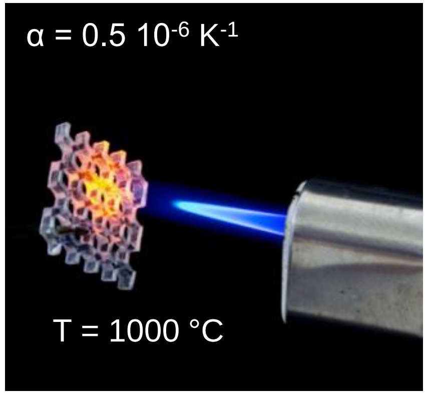
XPS



Hardness (Vickers)

Glassomer: 980 HV
Comm. fused silica: 800 HV

Thermal Resistance



Surface Properties

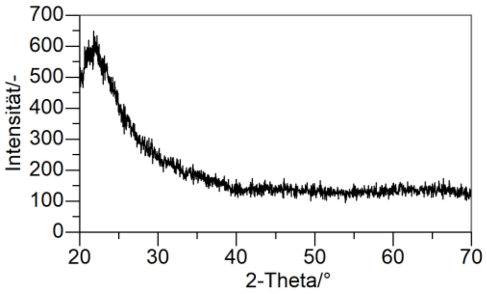
γ = 60.4 ± 0,14 Jm^{-2} Θ_{H2O} ~ 30°

commercial fused silica

γ = 59.4 ± 0.52 Jm^{-2} Θ_{H2O} ~ 30°

Glassomer® fused silica

XRD



Bending strength

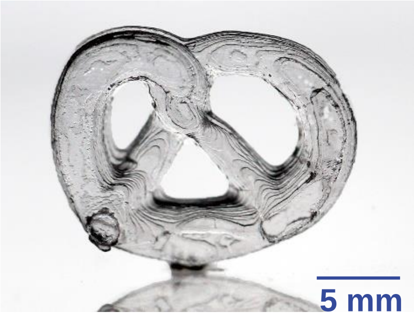
Glassomer: 115 MPa
Comm. fused silica: 100 MPa

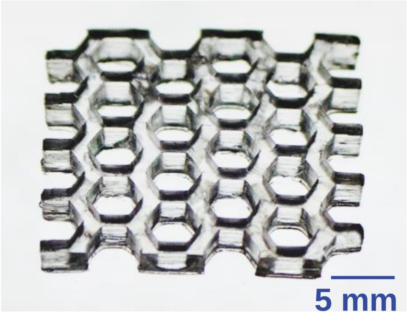
Kotz *et al.*, Nature **2017**

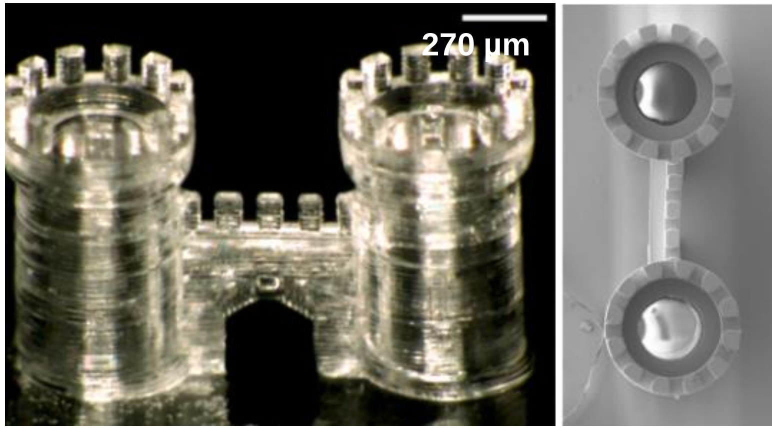
Glassomer® 3D Printing

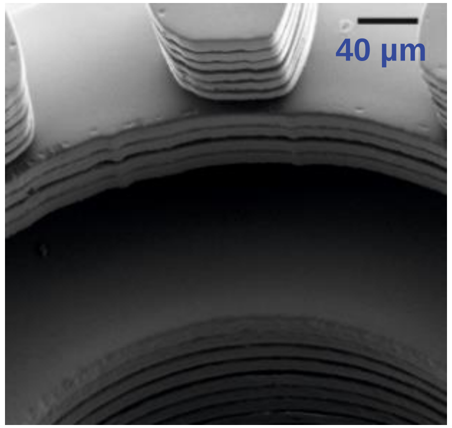
- Structure glass by using
  - liquid Glassomer®
  - off-the-shelf 3D printers
  - high resolution microstereolithography

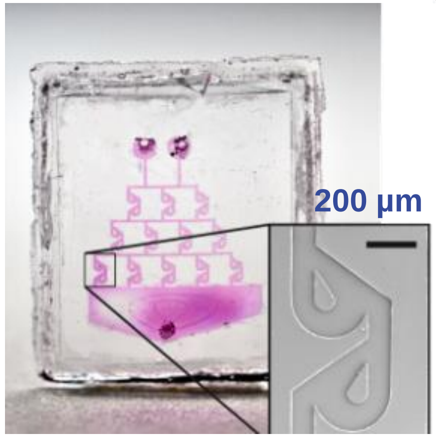
Kotz *et al.*, Nature **2017**







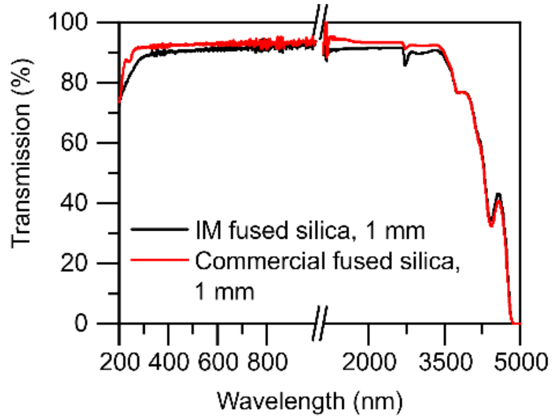




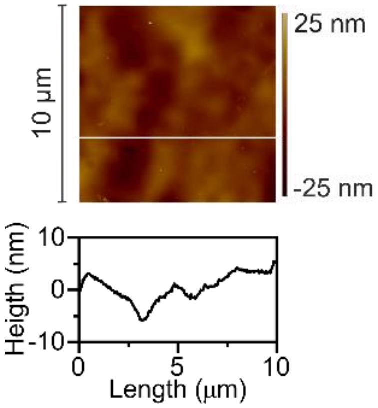
What about injection molding?

Powder injection molding

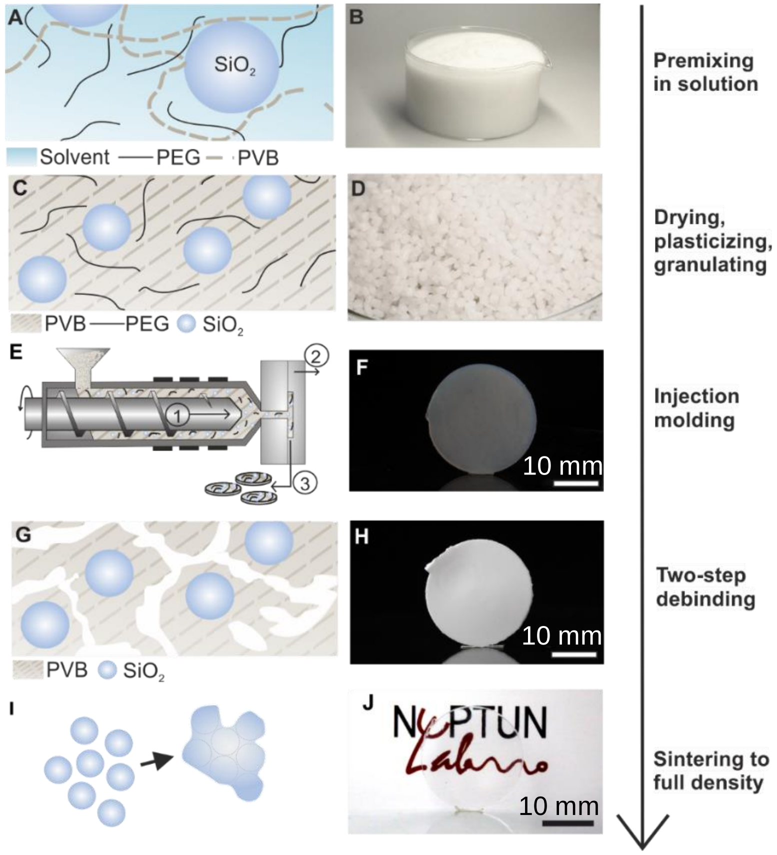
- Thermoplastic silica nanocomposites
  - Thermoplastic binder
  - Premixing step to avoid abrasion
- Processing temperature ~130 °C
- High-quality fused silica glass



R_q < 5 nm



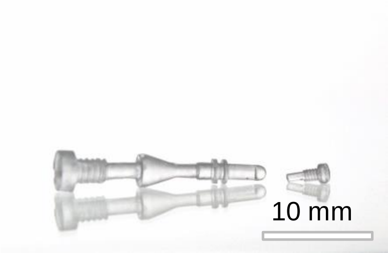
Mader, *Science*, **2021**



Mader, *Science*, **2021**

Injection molding of fused silica glass

Complex shapes



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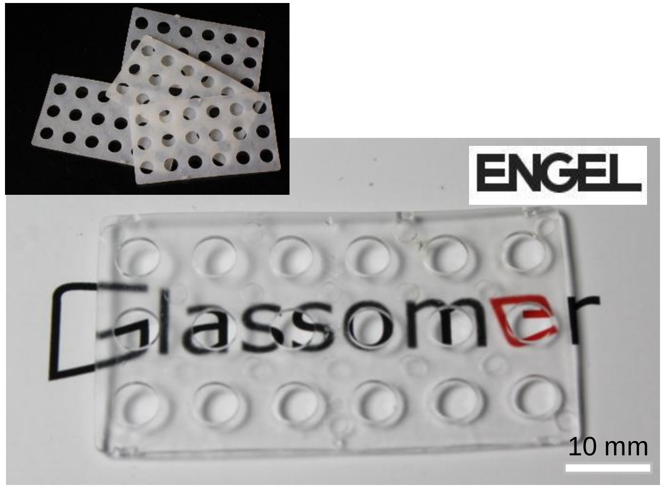
High-throughput, fully automated injection molding

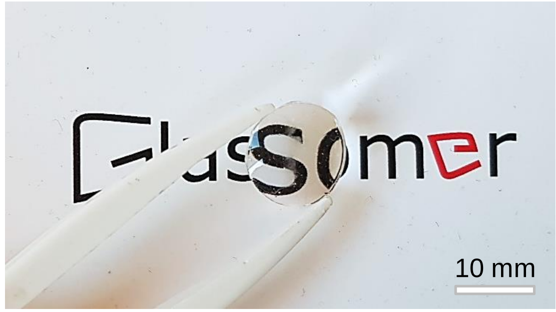
~5 s per piece

~8 s per piece



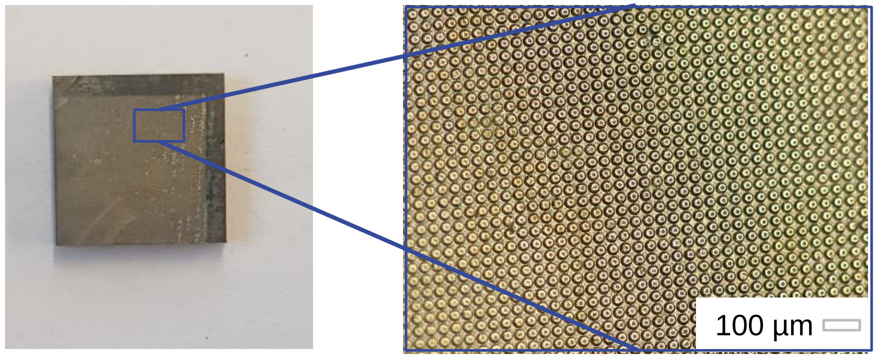
~15 s per piece

Optics



Injection molding of microstructured fused silica glass - Microoptics

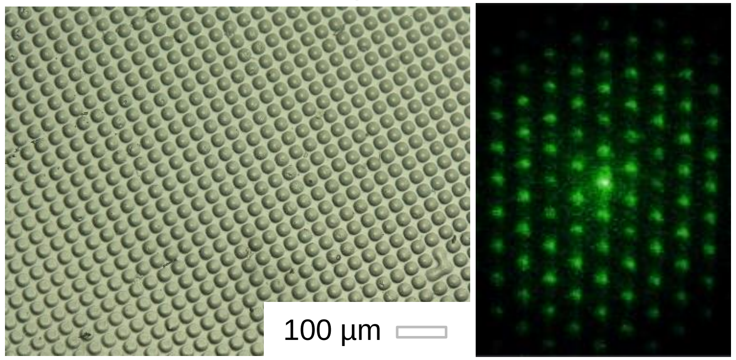
Micro structured metal mold inset



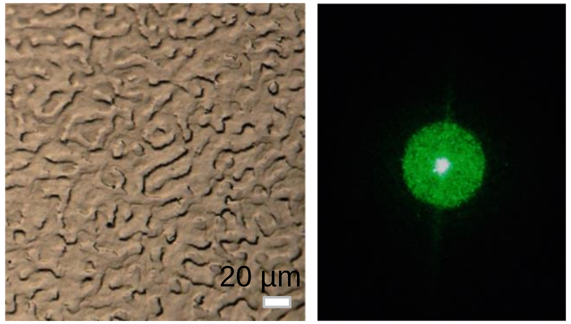
Glassomer injection molding

+ debinding and sintering

High resolution microstructures in fused silica glass



Diffractive optical elements



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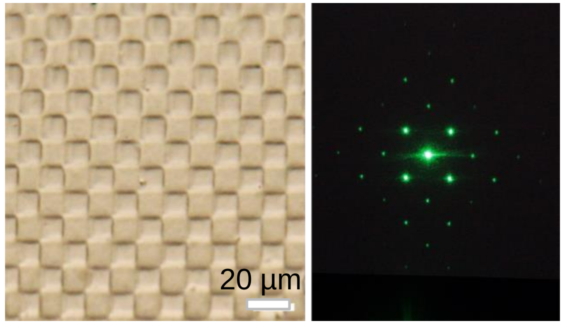
Checkerboard structure



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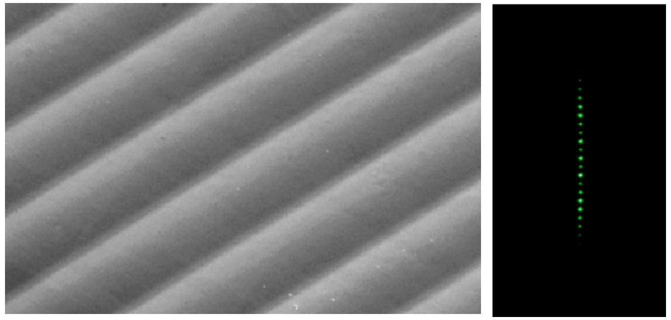
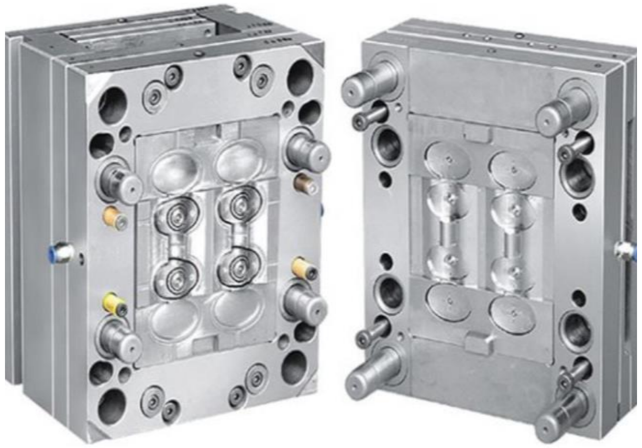
Cylindrical lens array



Mader, *Science*, **2021**

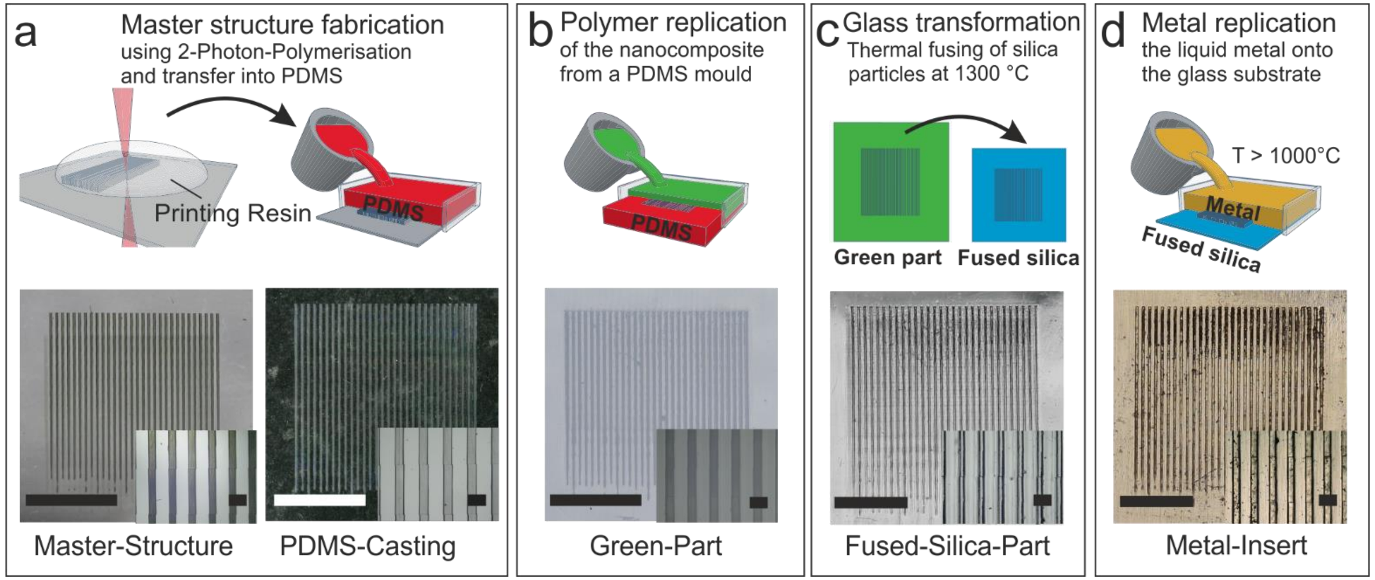
A problem which has been bothering me for a while: Injection molding tools



- Instrumental for injection molding
- Usually cost-critical step (> 50.000 €)
- Usually made via CNC machining

Idea: Transform tool manufacturing from an expensive and time-consuming subtractive process to a fast and flexible replicative process.

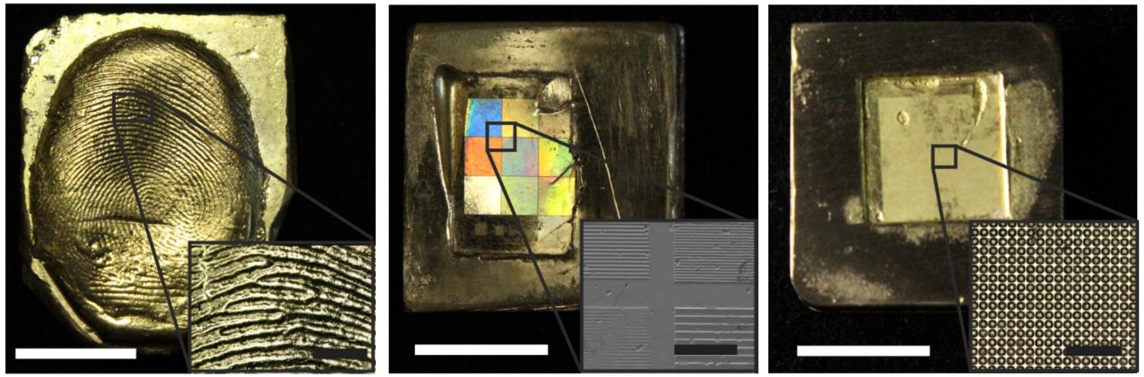
Aim: Generation of optical surfaces and structures in the single-digit micrometer range in metal through replication.



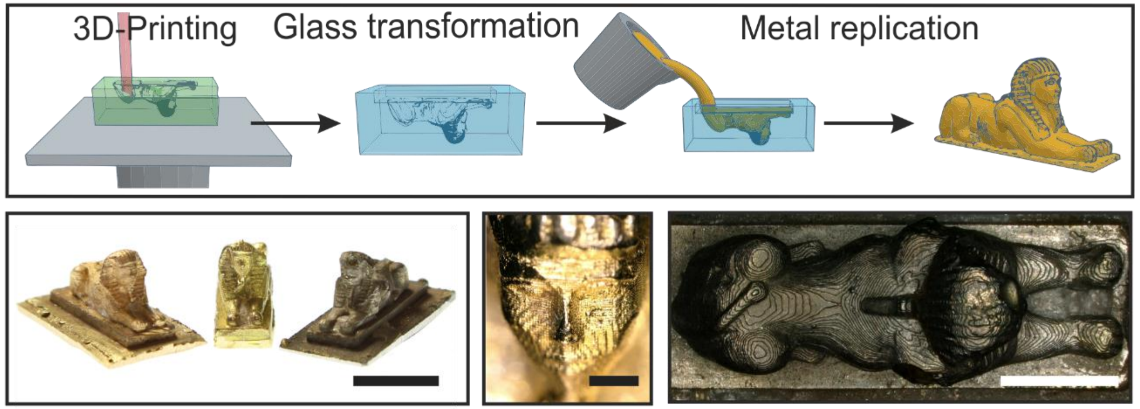
a. Fabrication of the master structure and replication in PDMS
b. Replication with polymer nanocomposite
c. Glass transformation
d. Metal replication from glass

From Nature and Technology

- Replicating structures from Nature, like finger prints
- Replicating structures from technology, like DOE’s or MLA’s

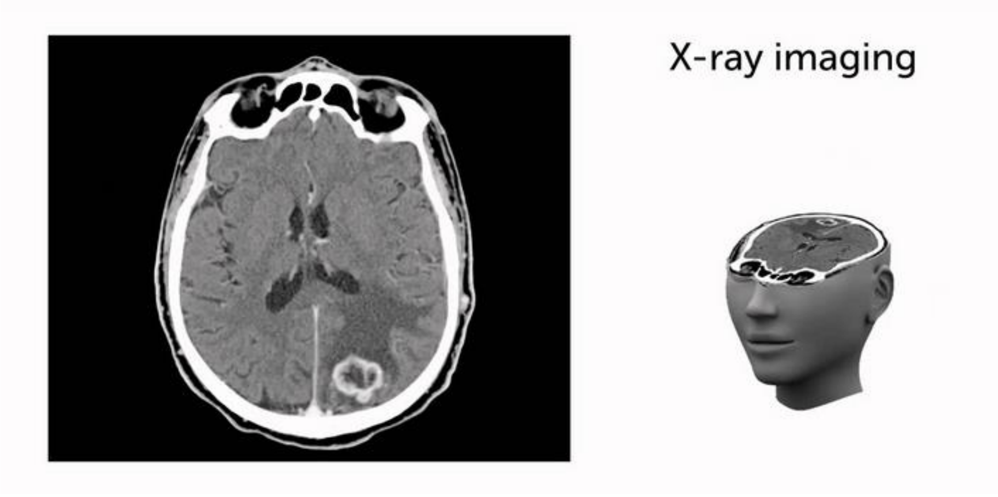


- Using commercial 3D-Printer for printing glass nanocomposite moulds
- Glass transformation using thermal processing
- Replicating 3D- Figures with metal by casting

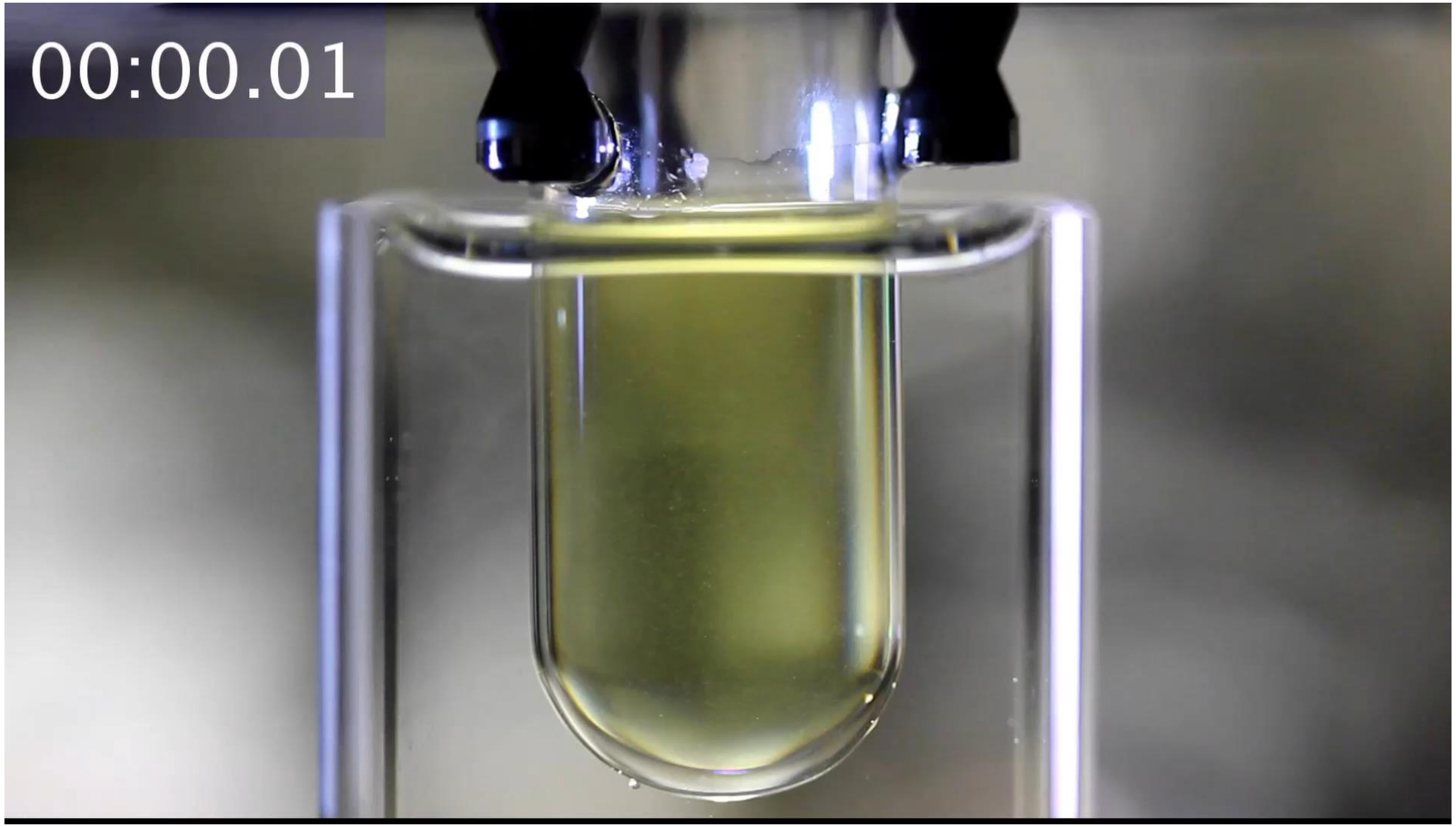


Volumetric Printing

- the most recent trend in 3D Printing is Volumetric Printing
- instead of stacking 2.5-dimensional layers to approximate 3D objects, these techniques try to generate the object in a volume at the same time
- for light-based structuring, these means that a 3D light pattern must be generated in space instead of a 2D structure as commonly used in lithography



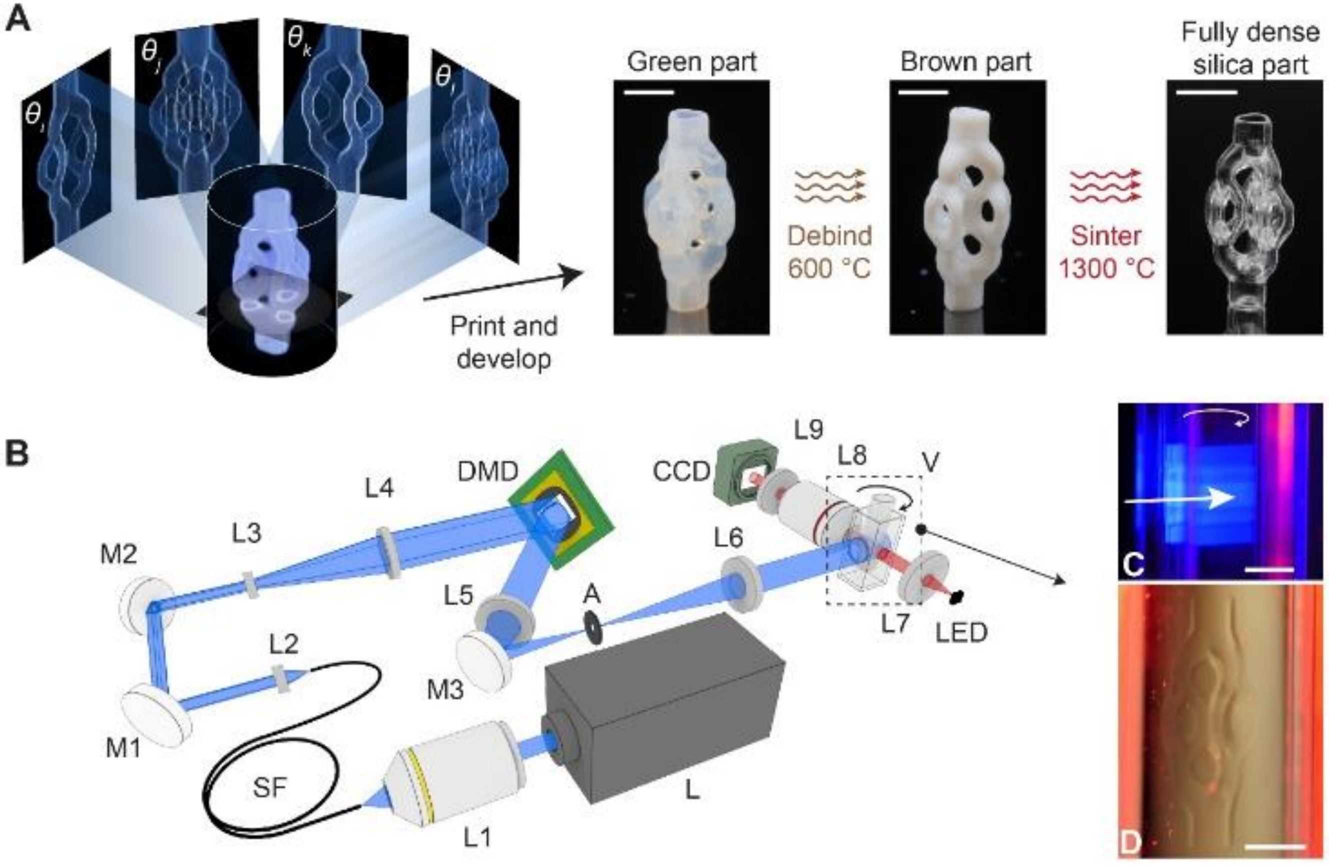
Printing an object via CAL

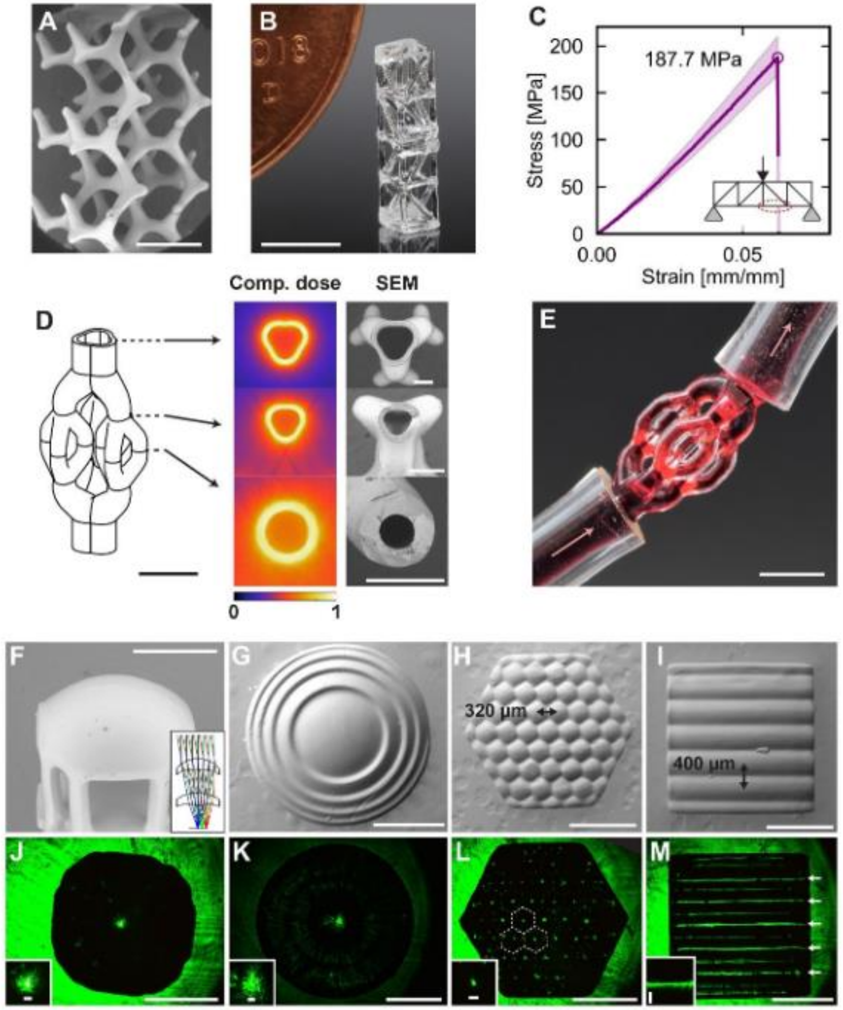


Kelly et al., Science, 2019

- as can be seen, the object only appears towards the end of the print
- suppressing polymerization before this point is important
- center areas catch an overall higher dosage and thus are more prone to polymerize to early
- this is why the resin is usually strongly inhibited

Glassomer meets CAL





Toombs *et al*., Science, **2022**

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COVER: A glass structure about 4.5 mm tall with features as small as 0.25 mm is 3D printed with microscale computed axial lithography followed by high-temperature sintering. The process enables the synthesis of highly transparent and inert glass parts with fine details, which are useful for a variety of applications. See page 308....

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Acknowledgements

Thank you for your attention!

NeptunLab

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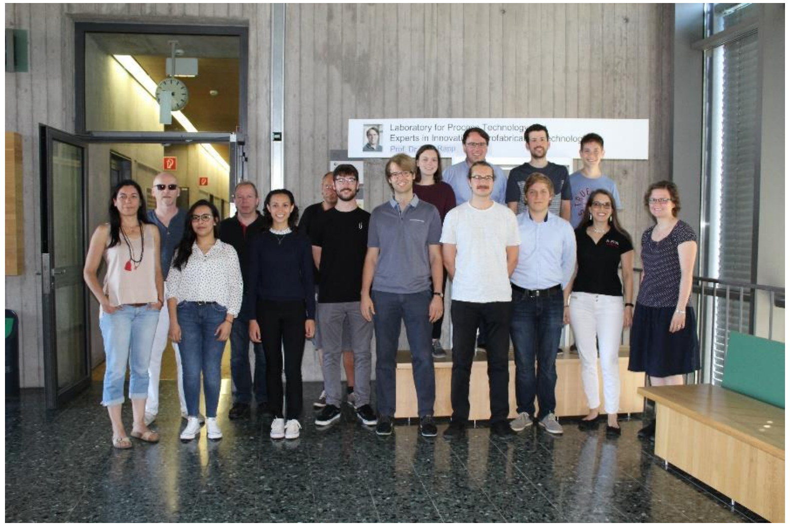

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