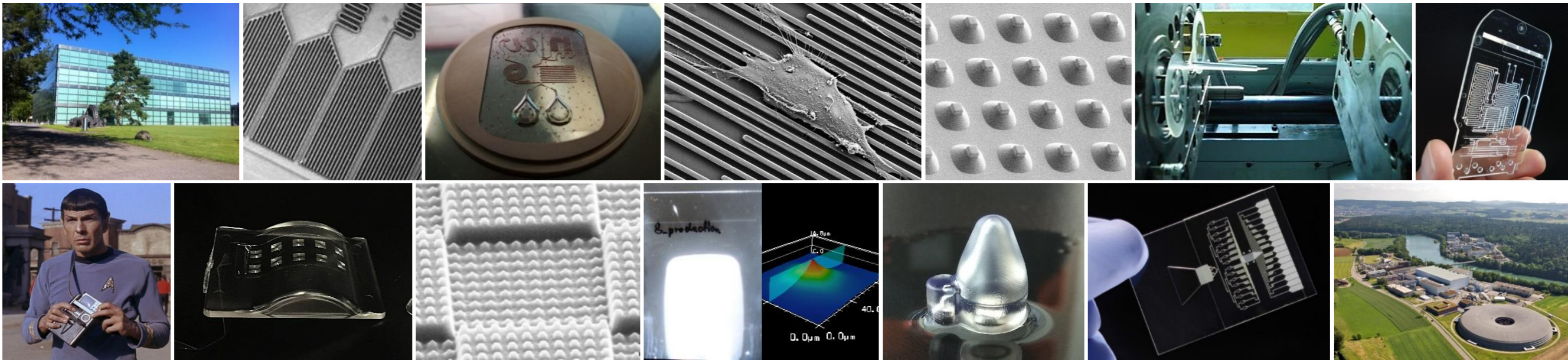


# Mittels Oberflächenstrukturierung zu neuen Funktionalitäten

OST Coffee Lecture Series – 1.07.2021, online (Teams)



Prof. Dr. Per Magnus Kristiansen

Institut für nanotechnische Kunststoffanwendungen (INKA)  
Fachhochschule Nordwestschweiz (FHNW)

## **Inhalte**

- **INKA – ein Brückenschlag zwischen Reinraum & Technikum**
- **Industrielle Replikationstechnologien**
- **Ausgewählte Mastering-Technologien**
- **Freiform-Mikrooptiken**
- **Perforierte Membranen für die Proteinkristallographie**
- **Zusammenfassung**

## INKA – a meanwhile 15 year old „joint (ad)venture“ between FHNW & PSI

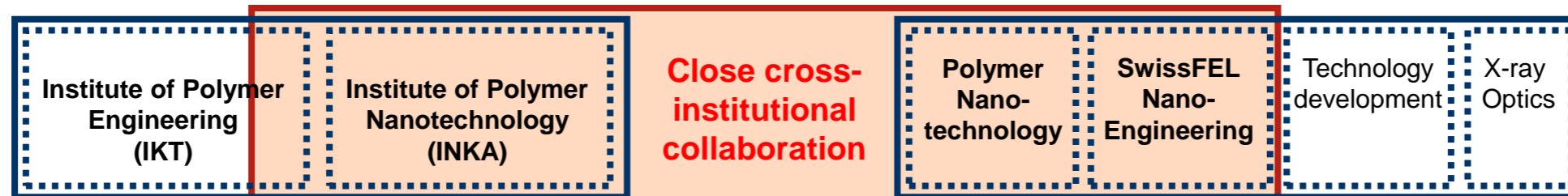


FHNW - IKT & INKA

← 10 km →

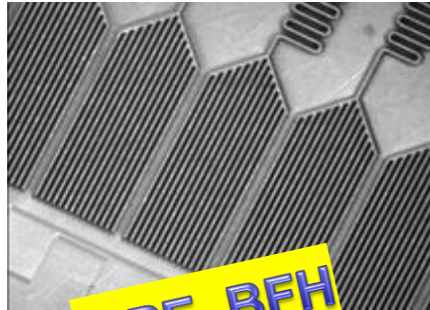


LMN – Laboratory for Micro- und Nanotechnology

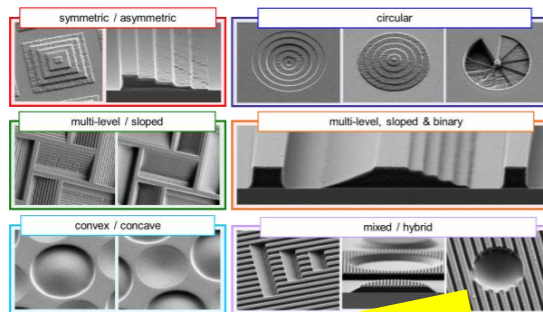
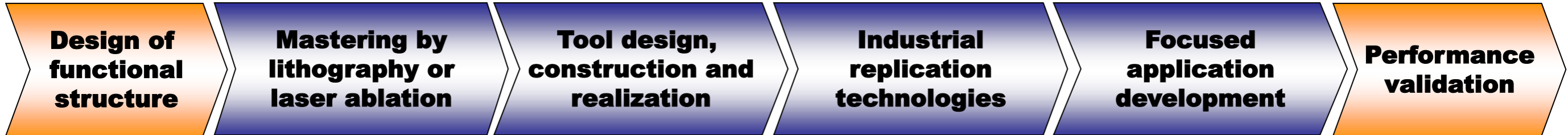
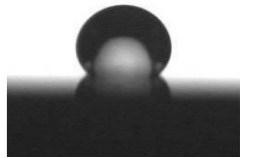
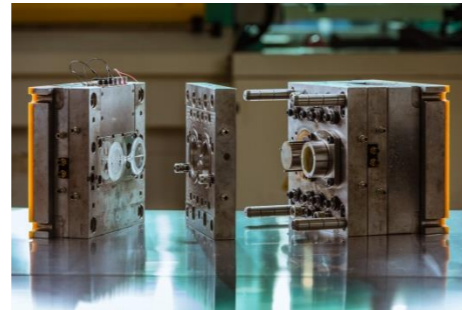


- Functionalization of polymer materials by**
- micro- and nanostructured surfaces
  - surface modification & coatings
  - nanoscale additives

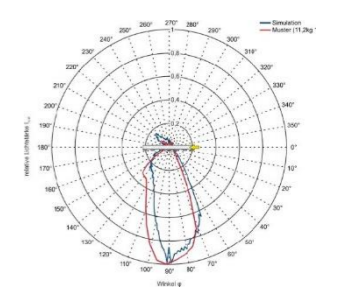
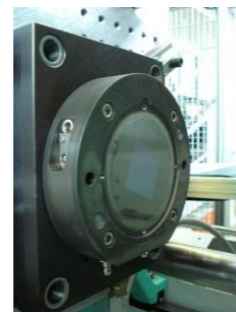
# The value chain of micro- & nanostructured polymer devices



**IPPE, BFH**

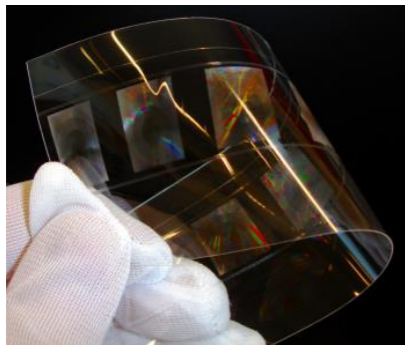


**PSI, CSEM, ...**

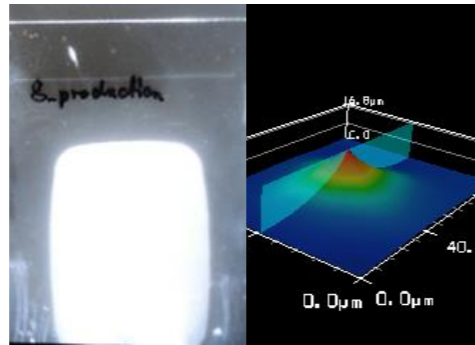


# Functional polymer surfaces by topographical structuring

pictures: INKA, Univ. Glasgow, CSEM



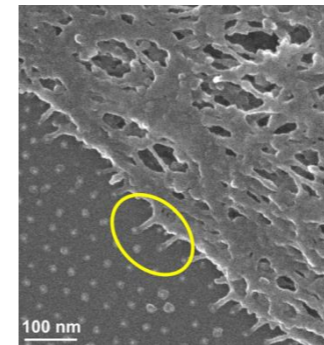
**DOE systems**  
features  $\sim 0.25\text{-}2\ \mu\text{m}$



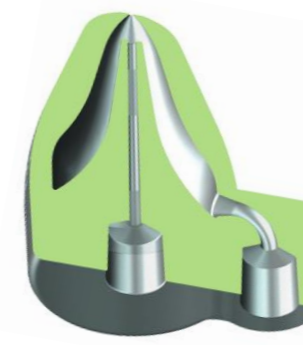
**Backlight display**  
features  $\sim 1\text{-}10\ \mu\text{m}$



**Microfluidics**  
features  $50\text{-}100\ \mu\text{m}$



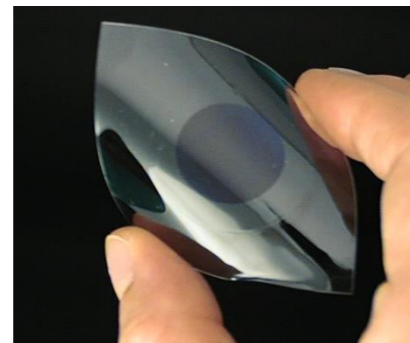
**implant surfaces**  
nm to  $\mu\text{m}$



**Droplet ejectors für PX**  
( $\mu$ -Stereolithographie)



**Holographic feature**  
submicron gratings



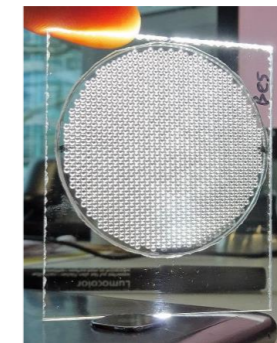
**Antireflex surface**  
line width  $\sim 150\ \text{nm}$



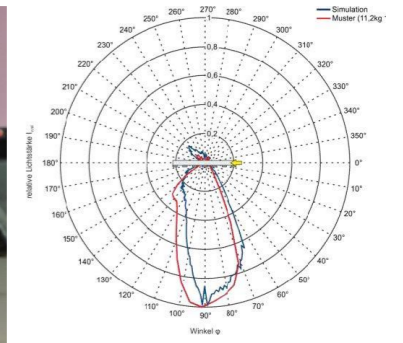
**Security features**  
line width  $\sim 180\ \text{nm}$



**DLWG polarizer**  
period  $\sim 70\ \text{nm}$



**Light directional elements**  
features  $20\text{-}70\ \mu\text{m}$

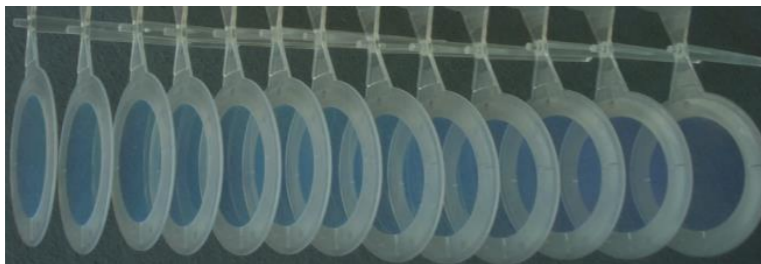


## Inhalte

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- **Perforierte Membranen für die Proteinkristallographie**
- **Zusammenfassung**

## Industrial replication technologies – injection molding

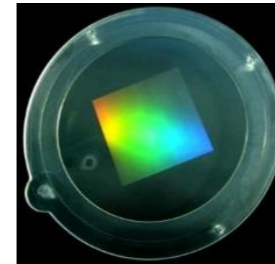
- Variothermal temperature control → Key for high fidelity replication
- Dedicated molding tools → **constant development**
  - Different part sizes up to 4 inch wafer
  - Tool sensors (pressure, temperature) ; online viscosity control
- Peripheral equipment & subsequent processes → **constant development**
  - bonding technologies, surface treatment
  - Assembling strategies
- Some examples from past R&D projects



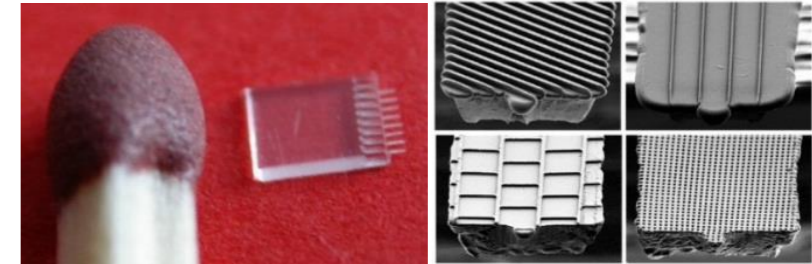
**Moth-eye structures**



**microfluidics**



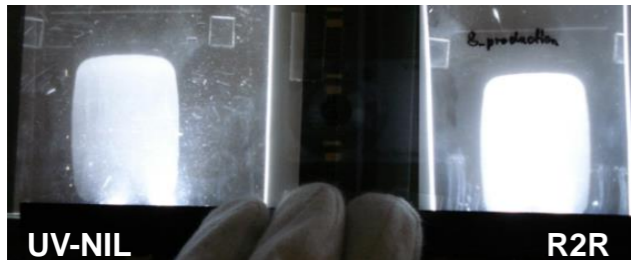
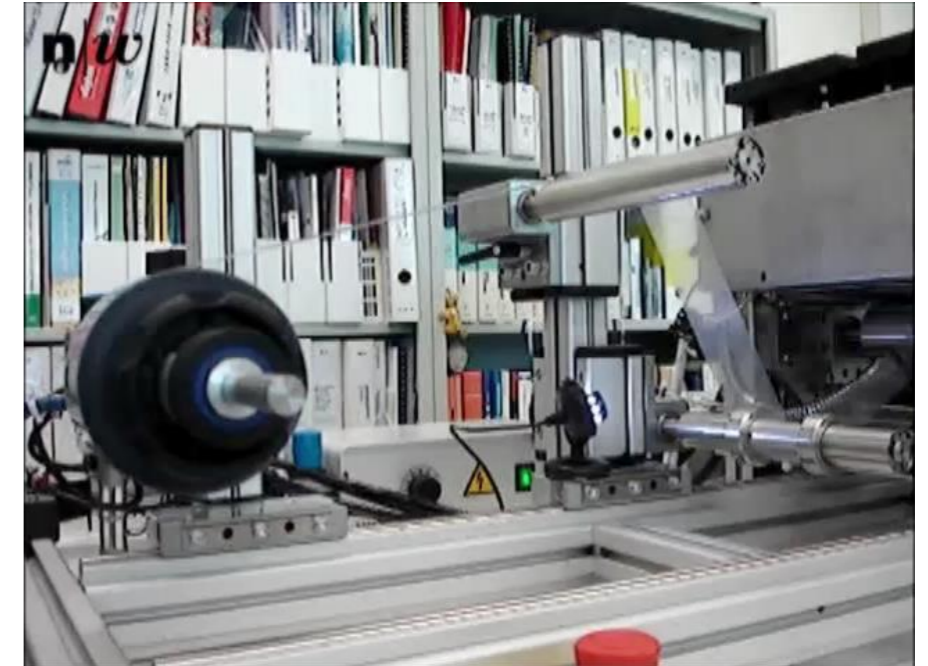
**nanopillars**



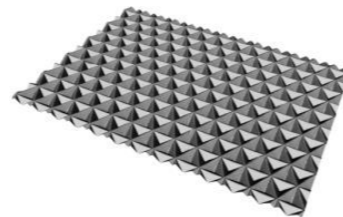
**microcantilevers**

## Industrial replication technologies - roll-to-roll thermal (nano)imprint lithography

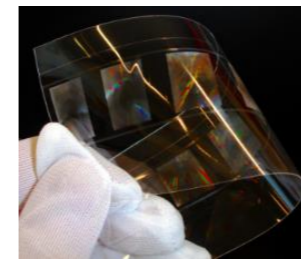
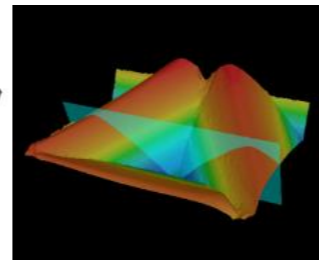
- **Designed & realized in-house** (MSE P7-P9 Urs Bruggisser)
  - System adaptations quite straight-forward
- **Highly automated setup with LabView interface**
  - Film tension and temperature control
- **Flexibility in master structure integration**
- *Masters:* Nickel shims, laser-structured steel rollers, or even high-performance polymer stamps (by hot embossing)
- **Parts realized to date**



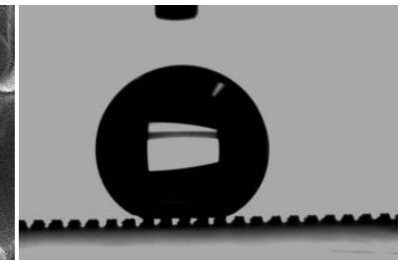
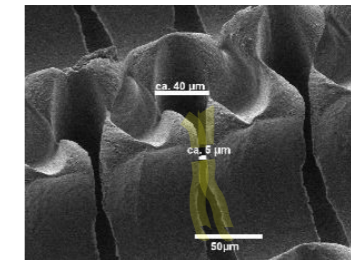
backlight displays



corner cube reflectors



DOE lenses



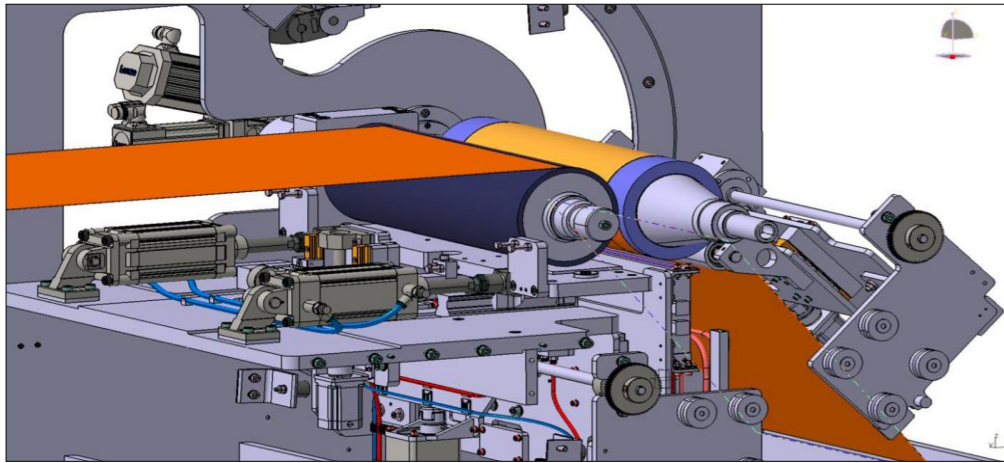
repelling surfaces



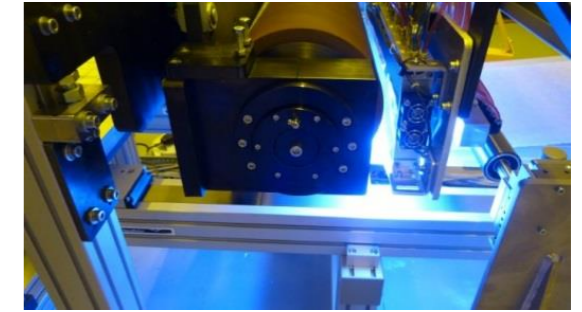
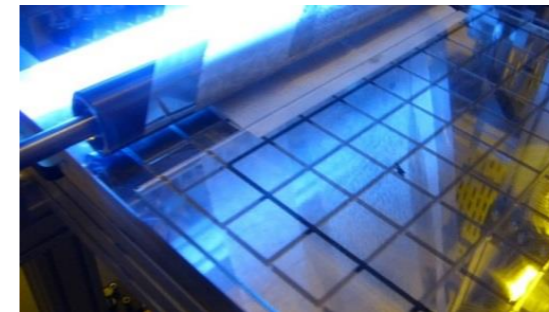
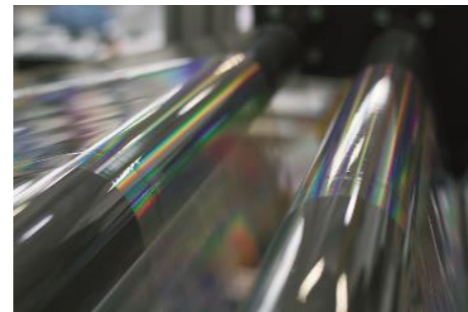
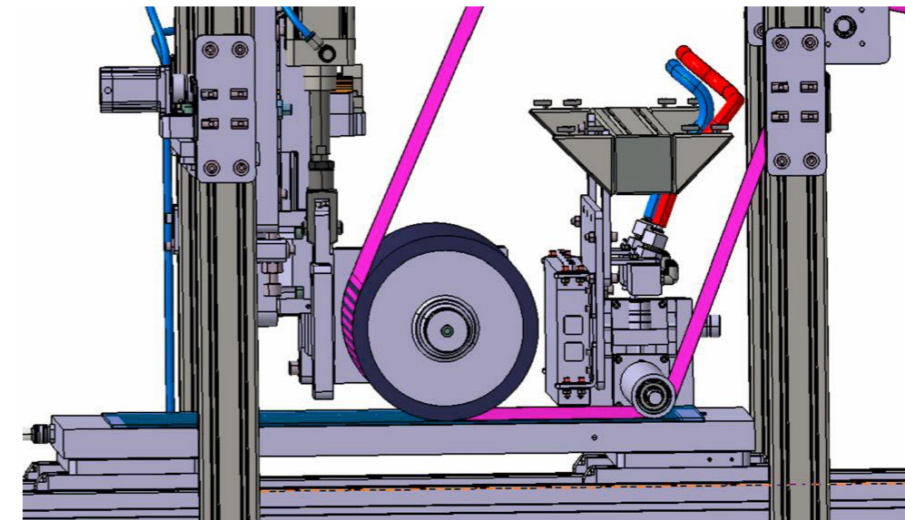
# Manufacturing of functional optical films by nanoimprint lithography (NIL)

Ref Temicon GmbH

## Roll-to-roll UV NIL

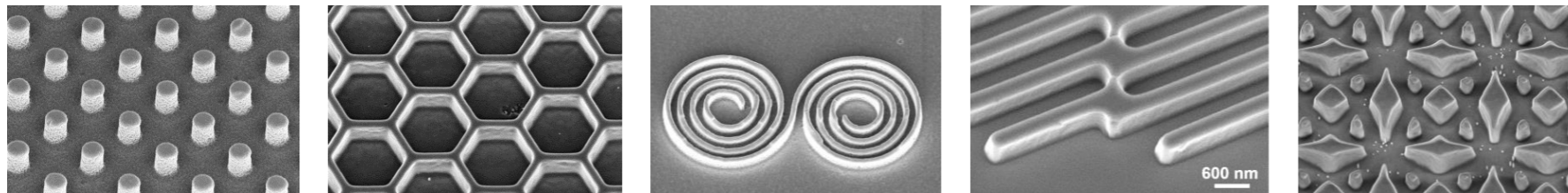
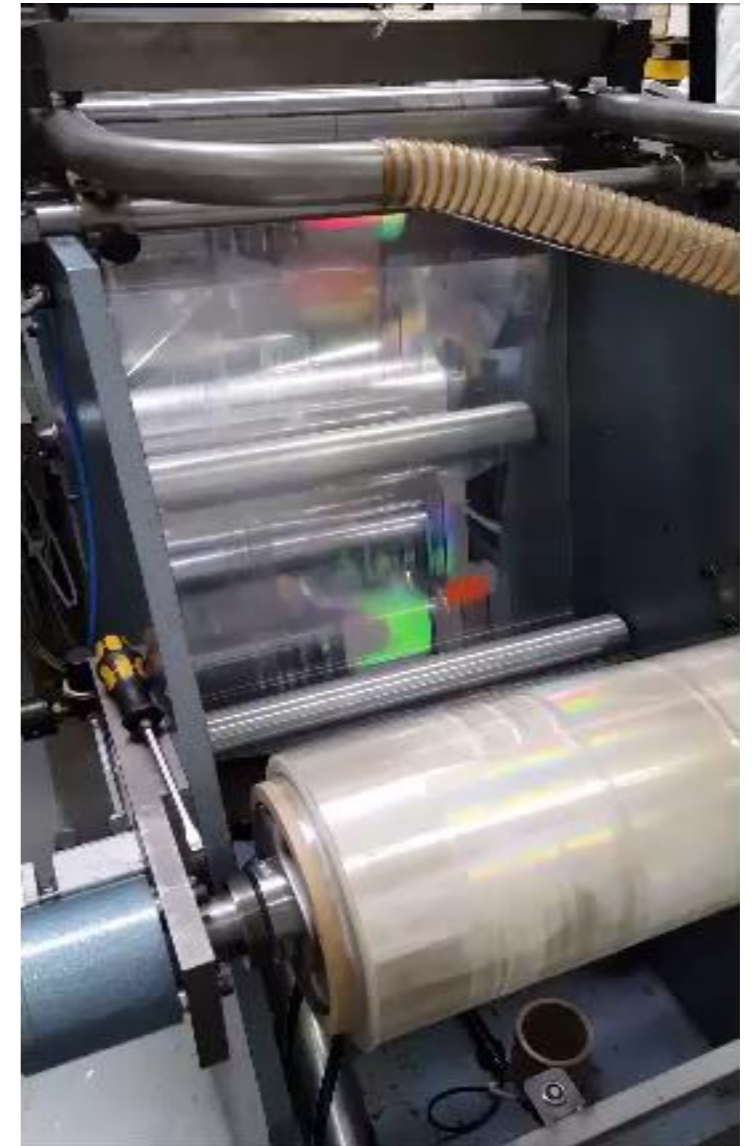
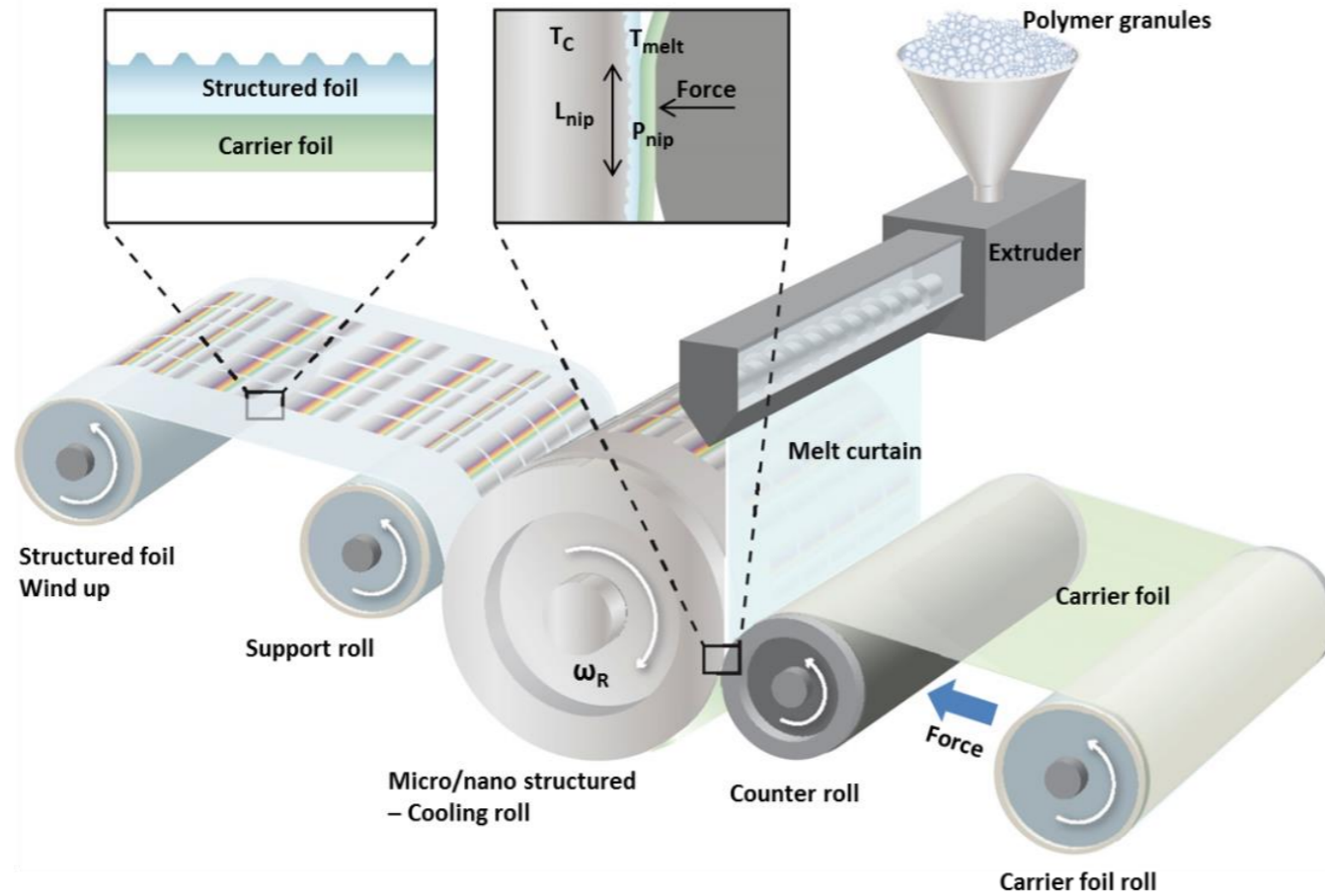


## Roll-to-plate UV NIL



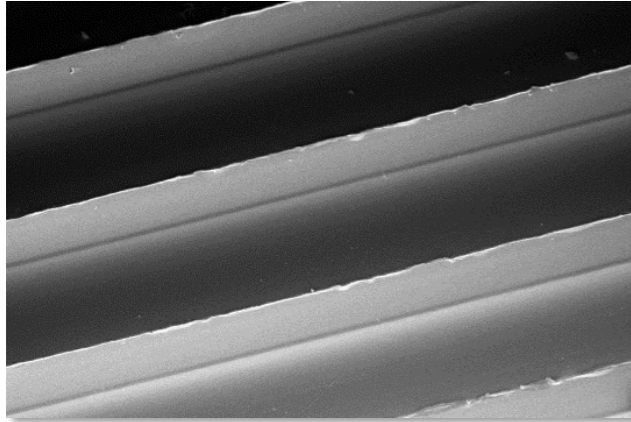
# Roll-to-roll extrusion coating – an interesting approach from Denmark

Ref: Murthy et al., Adv Eng Mater, (2015)



## Towards low cost concentrated solar power

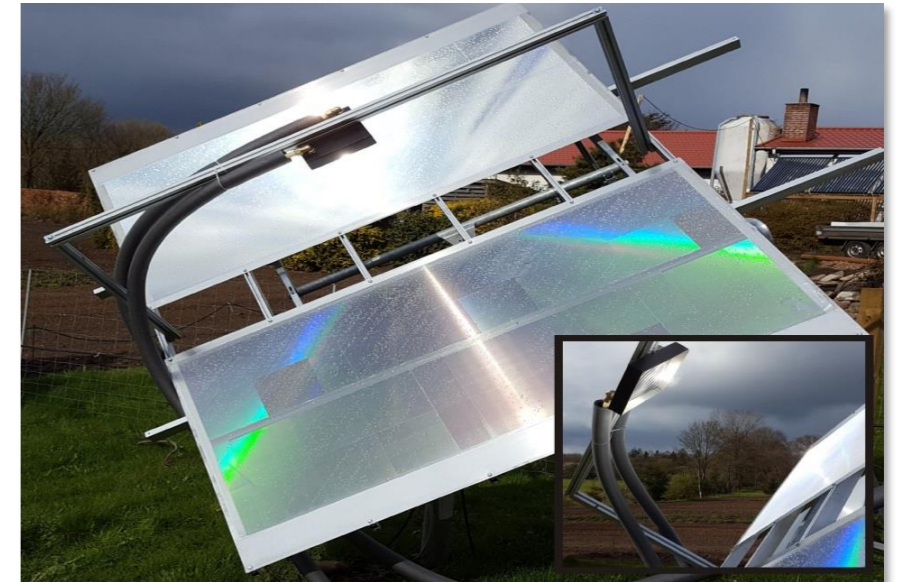
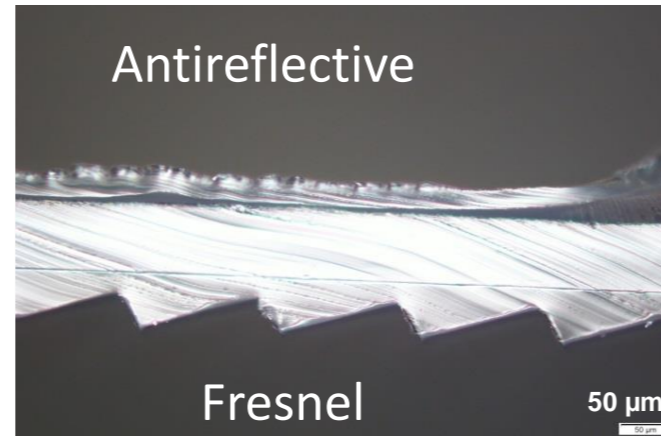
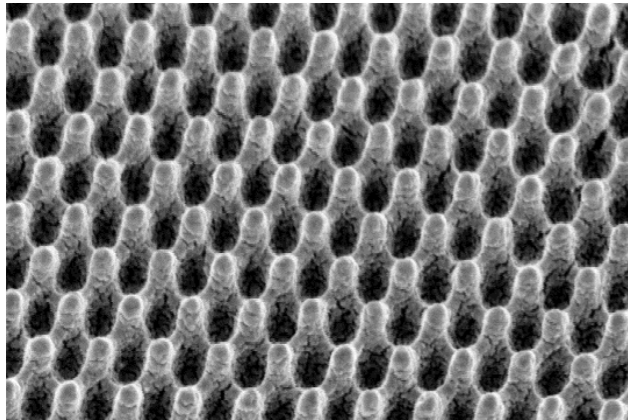
Reference: Matschuk et al., Presentation at PRN2016



Layer 1: Fresnel Lens

Layer 2: AR Structures

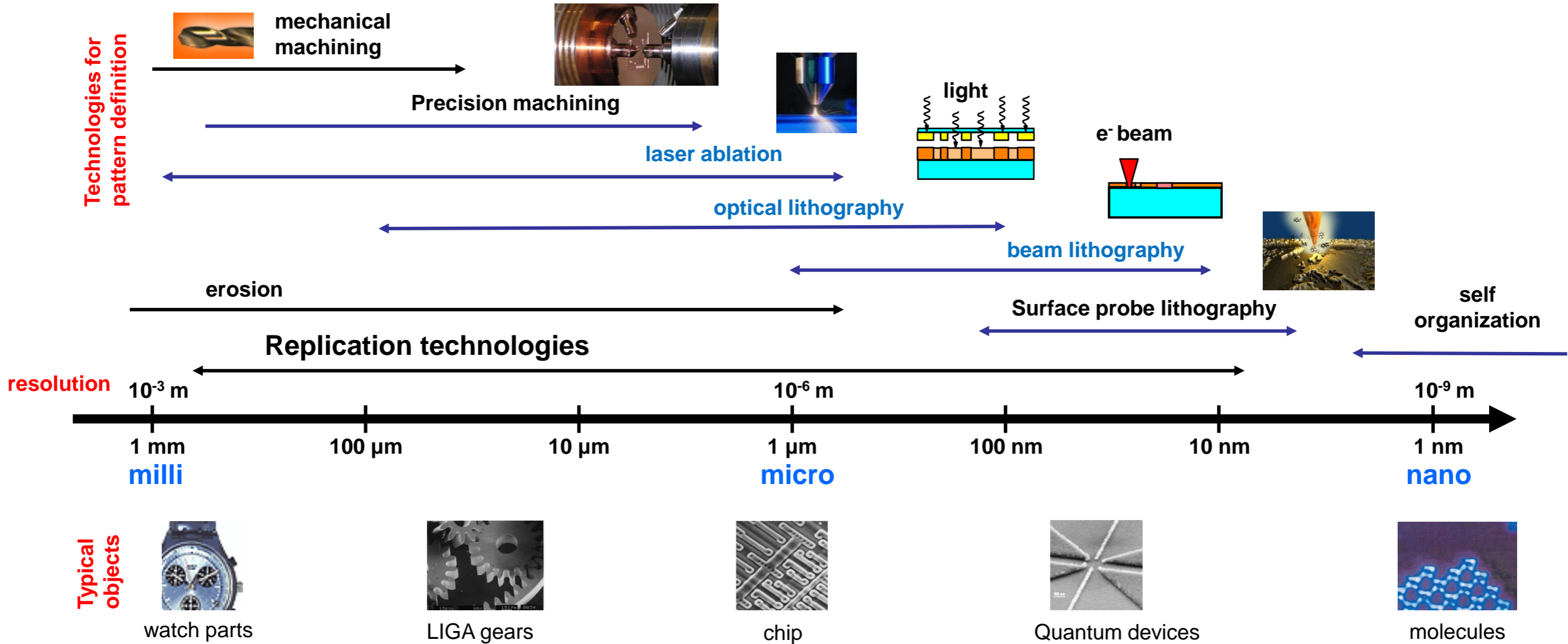
Master provided by Temicon GmbH



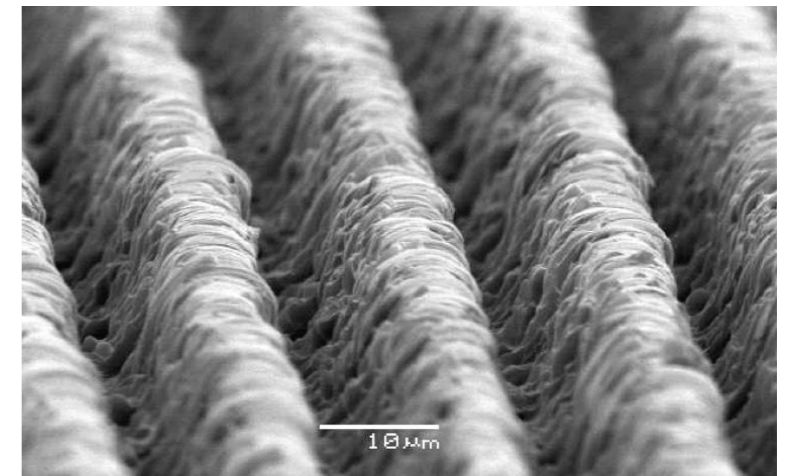
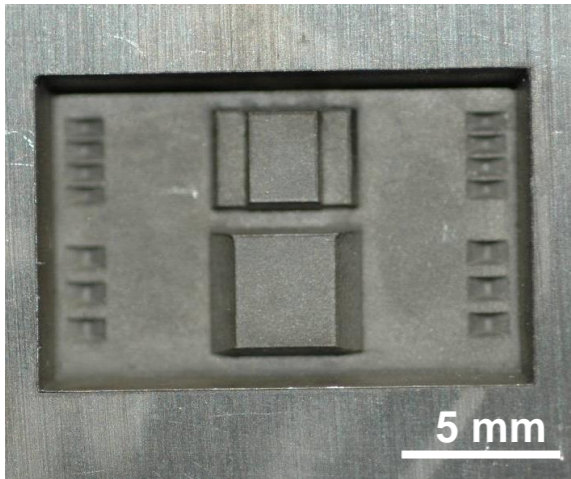
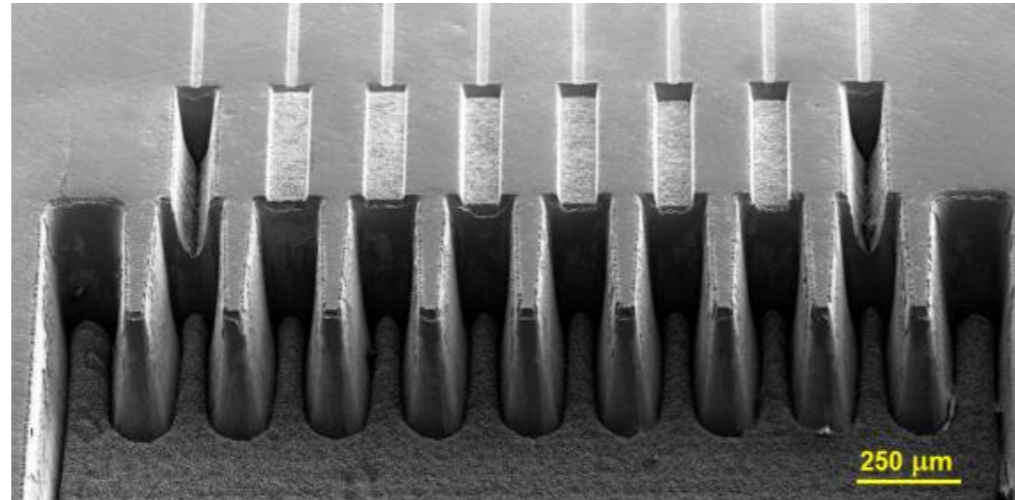
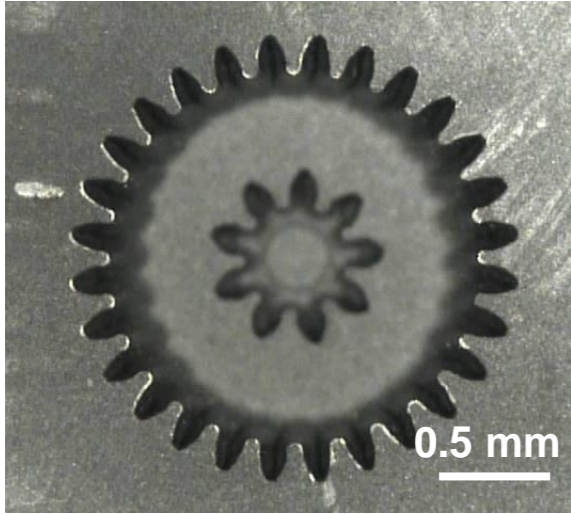
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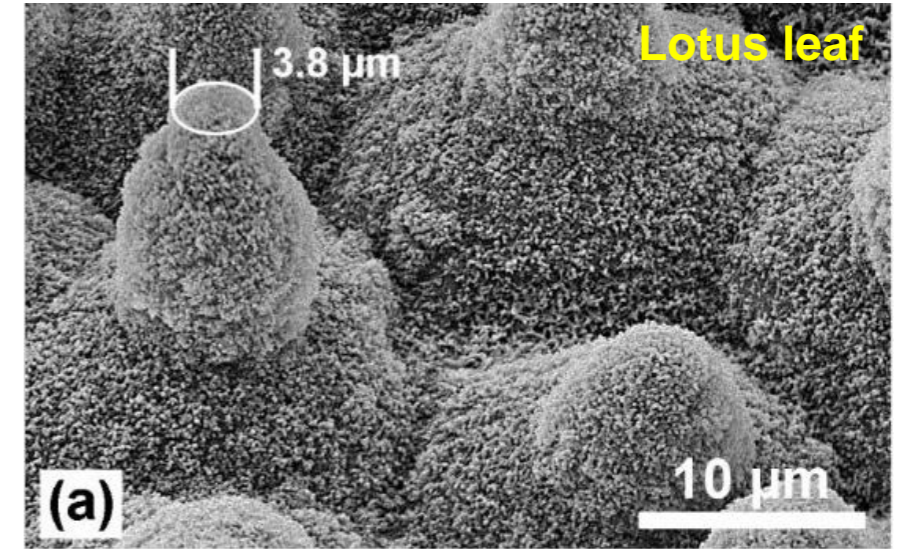
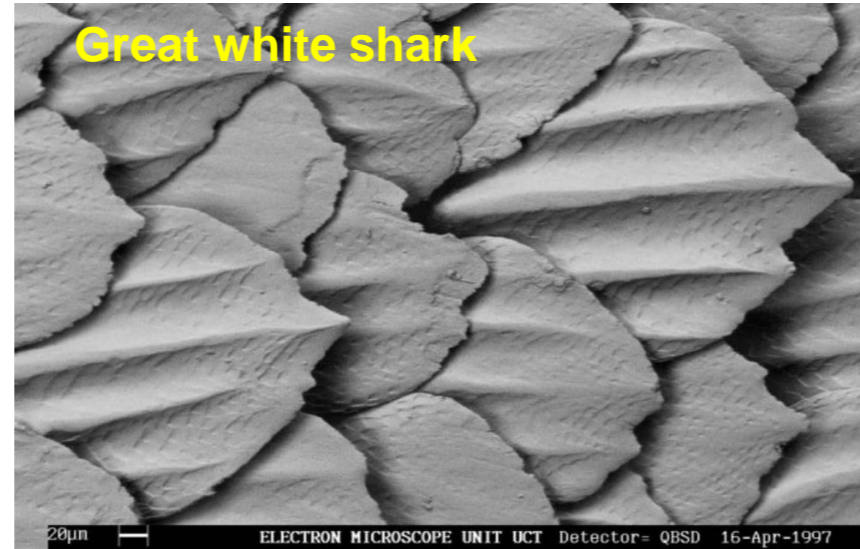
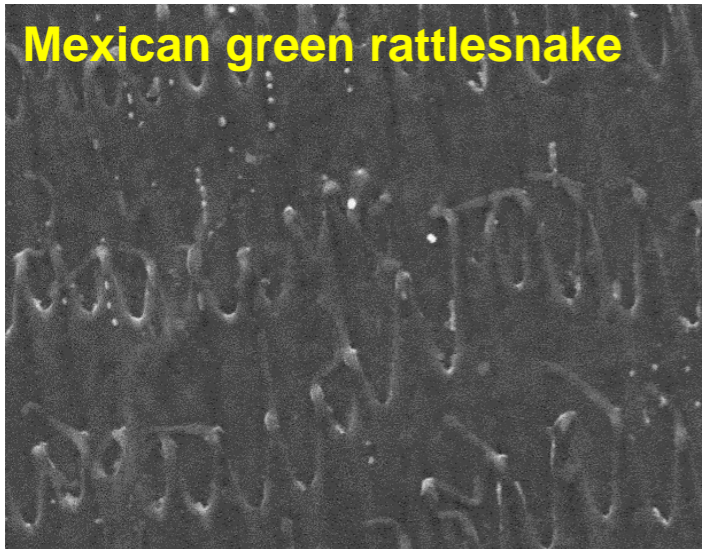
# Topographical structuring on different length scales



## Laser micromachining for manufacturing of mold inserts

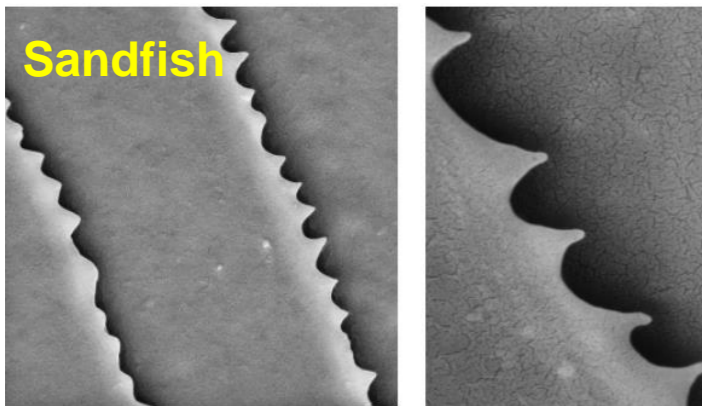


## Motivation for biomimetic surfaces – Structures with specific optimized properties in nature

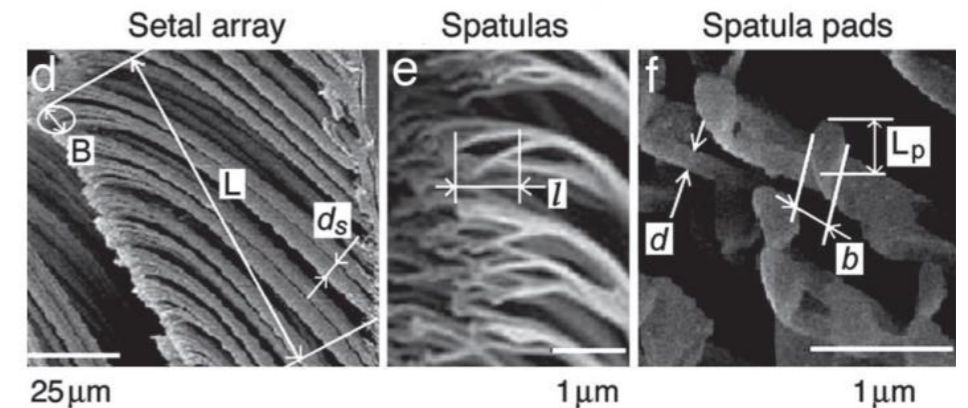
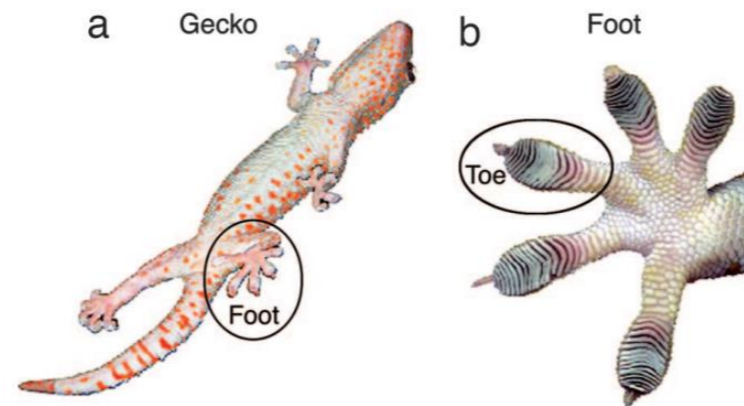


Trevor Sewell/Electron Microscope Unit, University of Cape Town

<http://www2.optics.rochester.edu/workgroups/cml/opt307/spr16/sanjay/IndexNew.html>



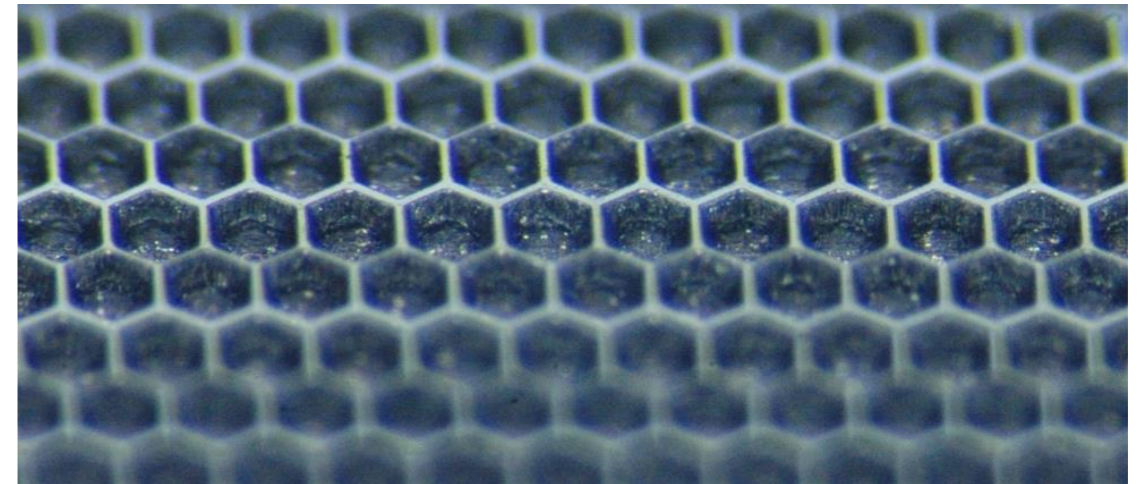
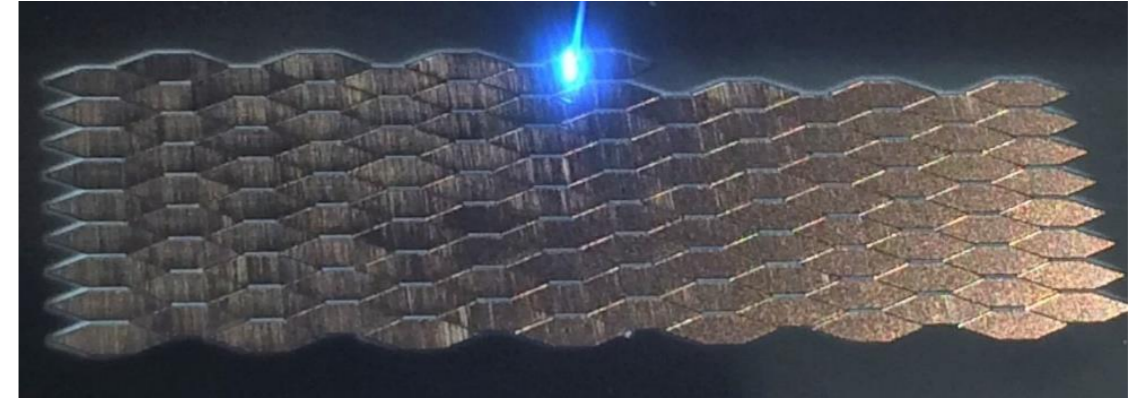
Rechenberg, I; El Khyari, A.; TU Berlin [1]



<http://www2.optics.rochester.edu/workgroups/cml/opt307/spr16/sanjay/IndexNew.html>

## Ultrashort pulse laser micromachining (alias laser ablation)

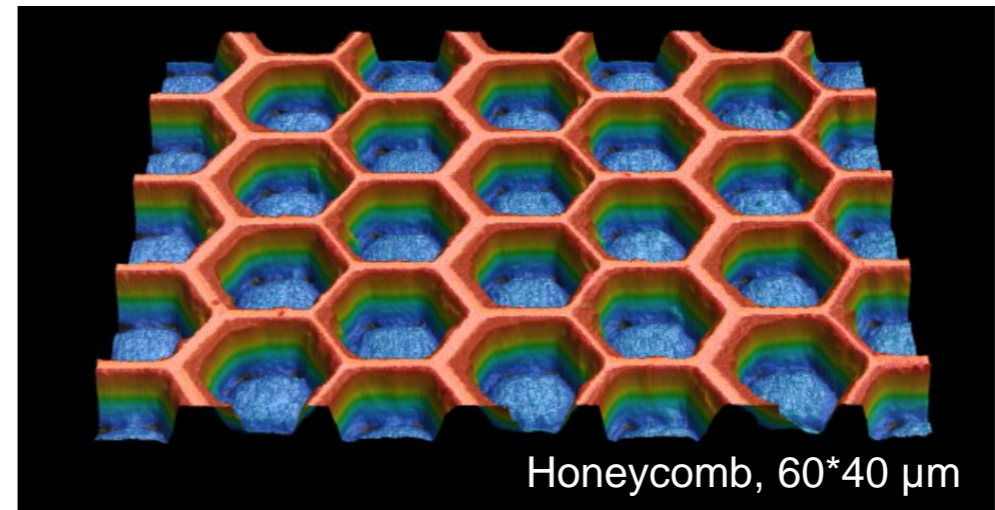
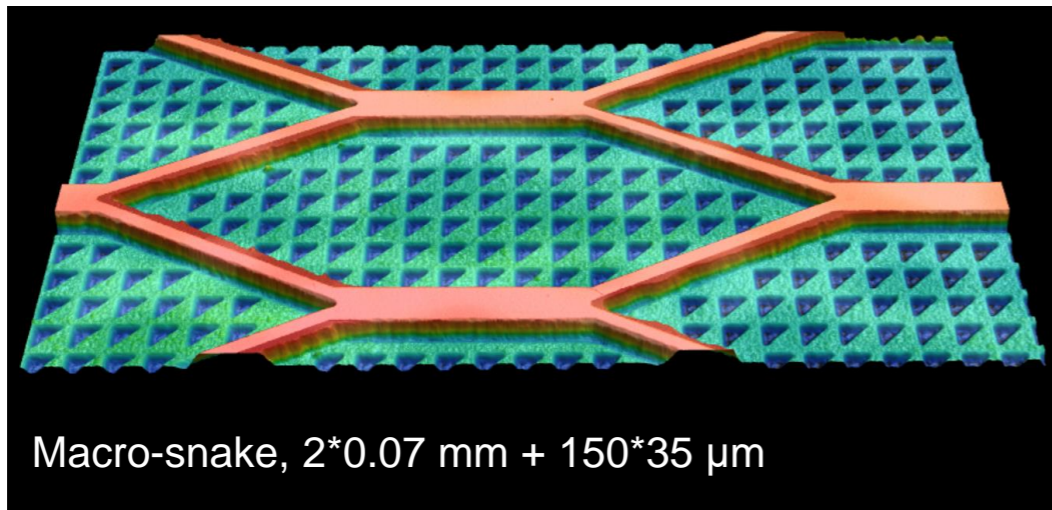
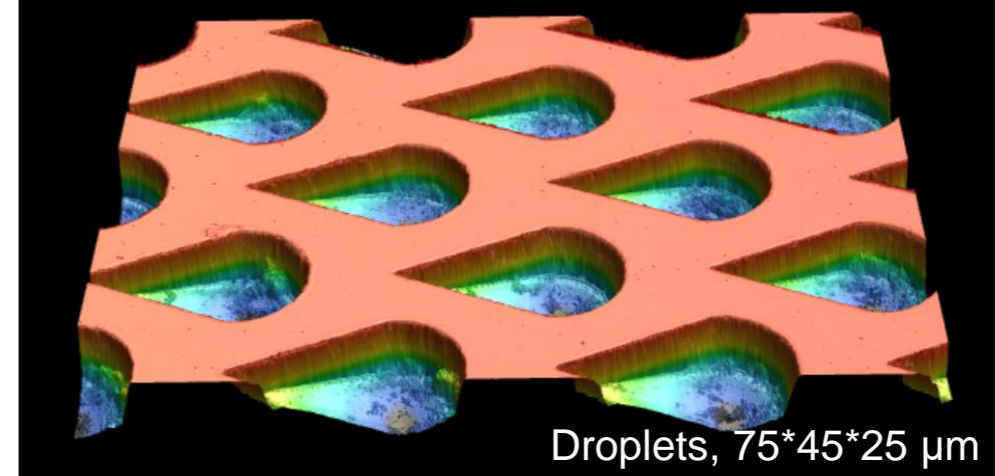
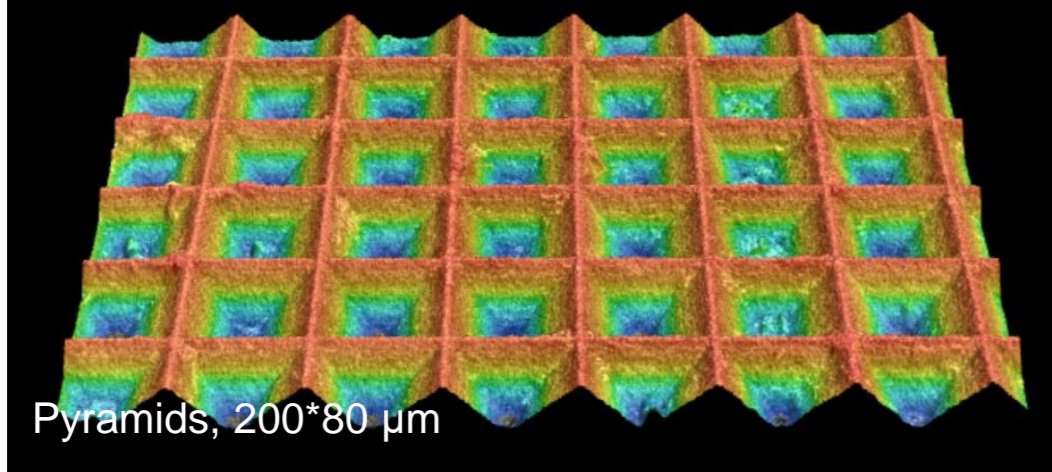
- **Ultrashort pulse lengths (fs to ps)**
  - Aiming for cold ablation
- **Different wavelengths**
  - UV, green, NIR
- **Variety of materials can be ablated (depending on wavelength)**
- **Applicable on cylinder surfaces**
- **Manufacturing parameters:**
  - Laser spot diameter  $\approx 12 \mu\text{m}$
  - Ca.  $1 \mu\text{m}$  ablation depth per run
  - Scanning speed 400 mm/s



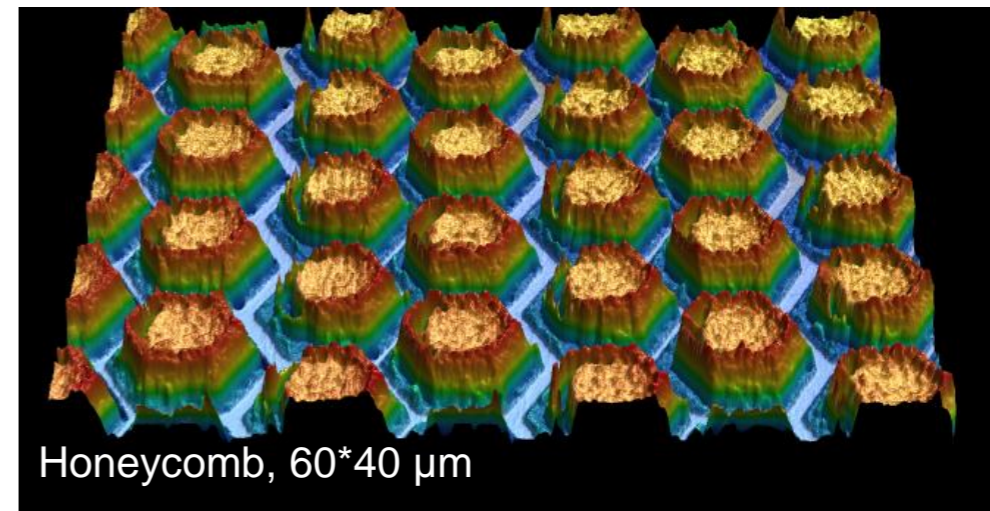
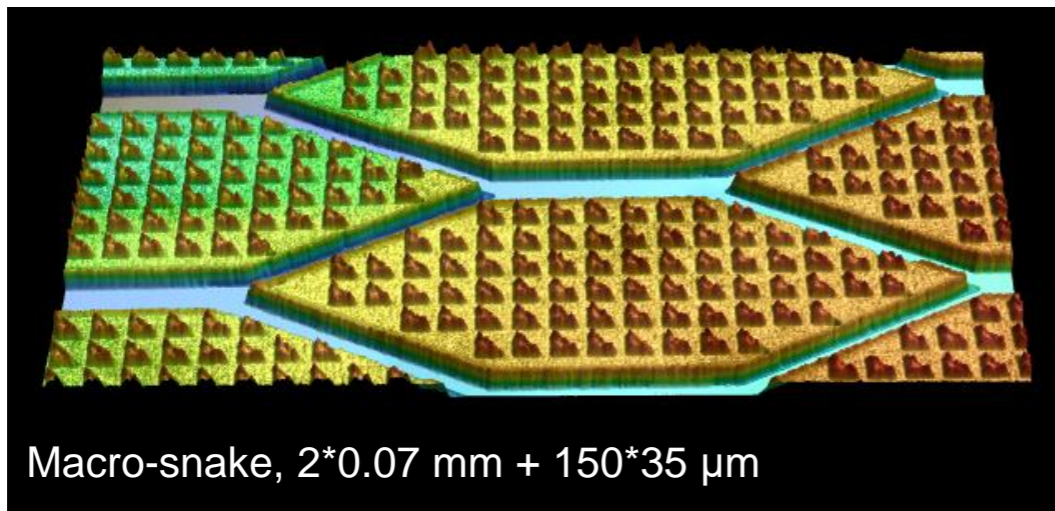
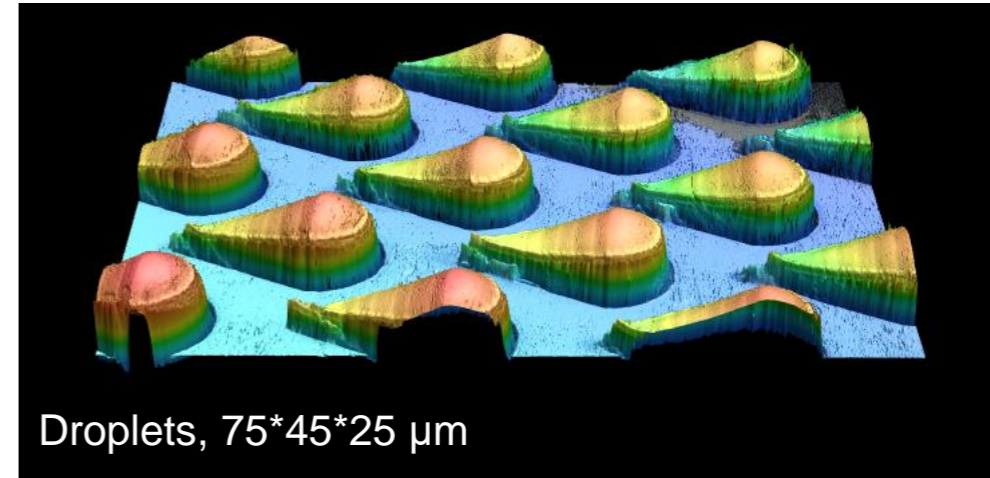
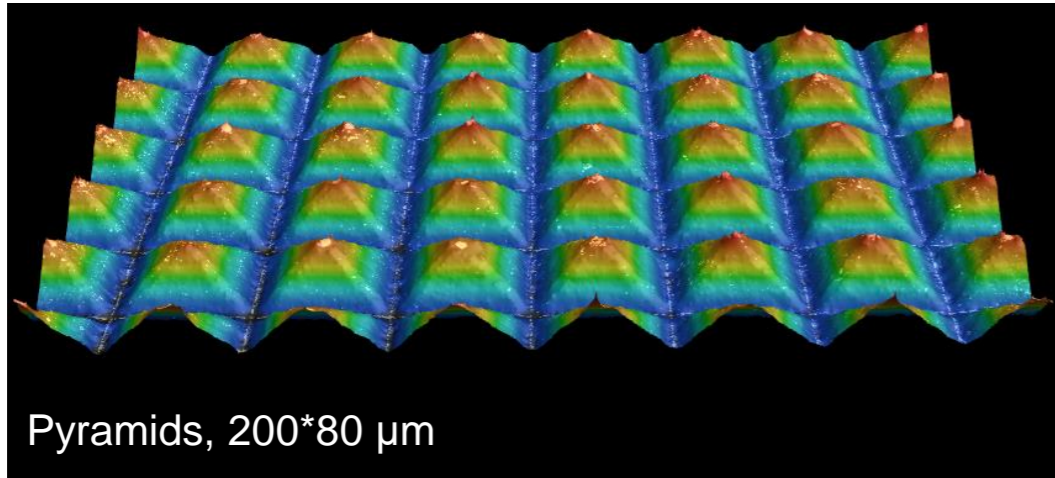
Macro photographs of honeycomb microstructure fabricated by pulsed UV laser ablation.  
Image credit: Armin Stumpp, IPPE @ FHNW



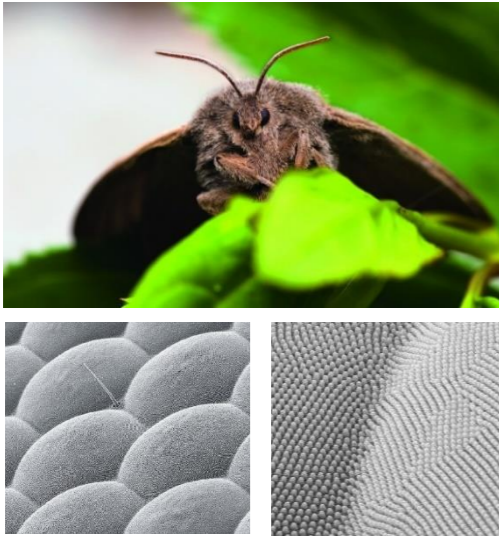
## Structures generated by laser ablation – master structures in steel



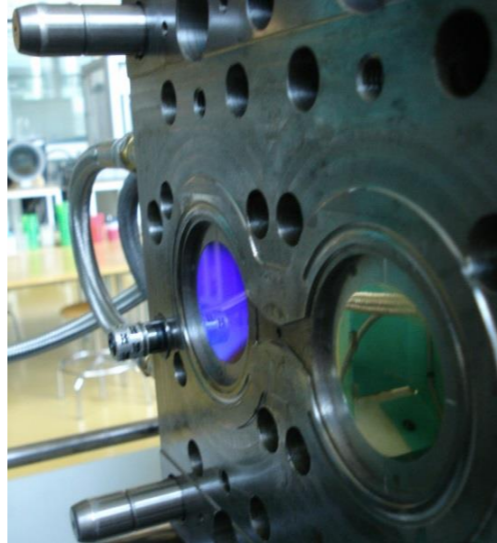
## Structures generated by laser ablation – replication in TPU → modification of friction behavior



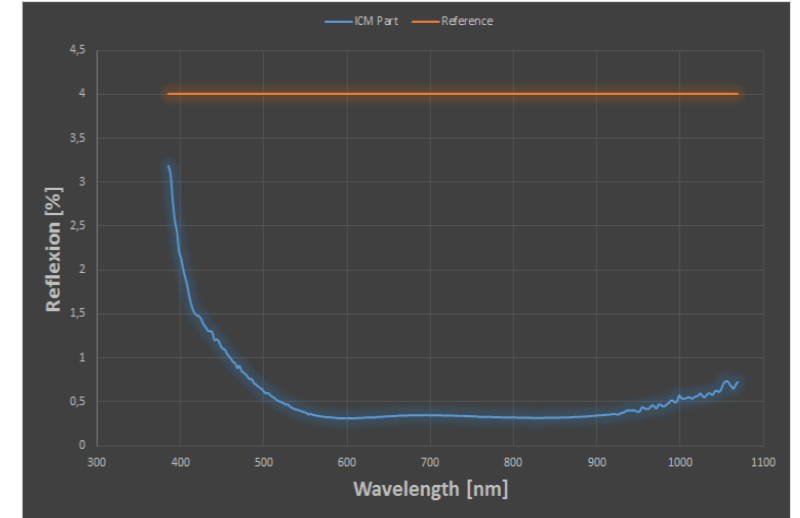
# Antireflective polymer surfaces inspired by the moth's eye topography



1. Inspiration from nature



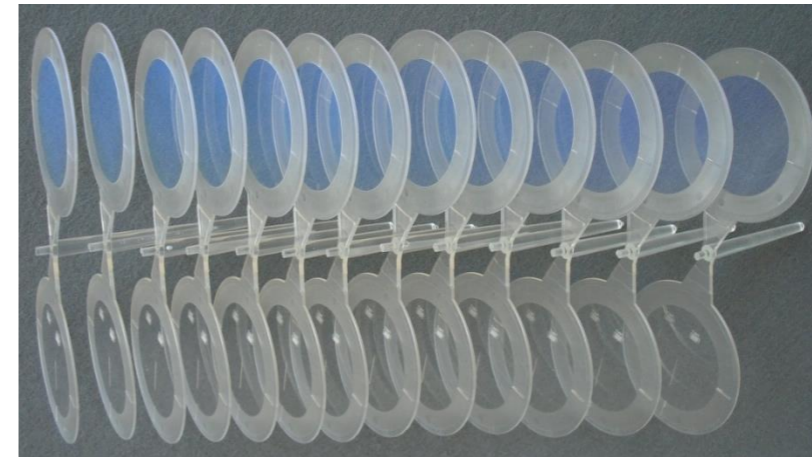
3. Ni-shim in molding tool



5. Optical reflection measurements



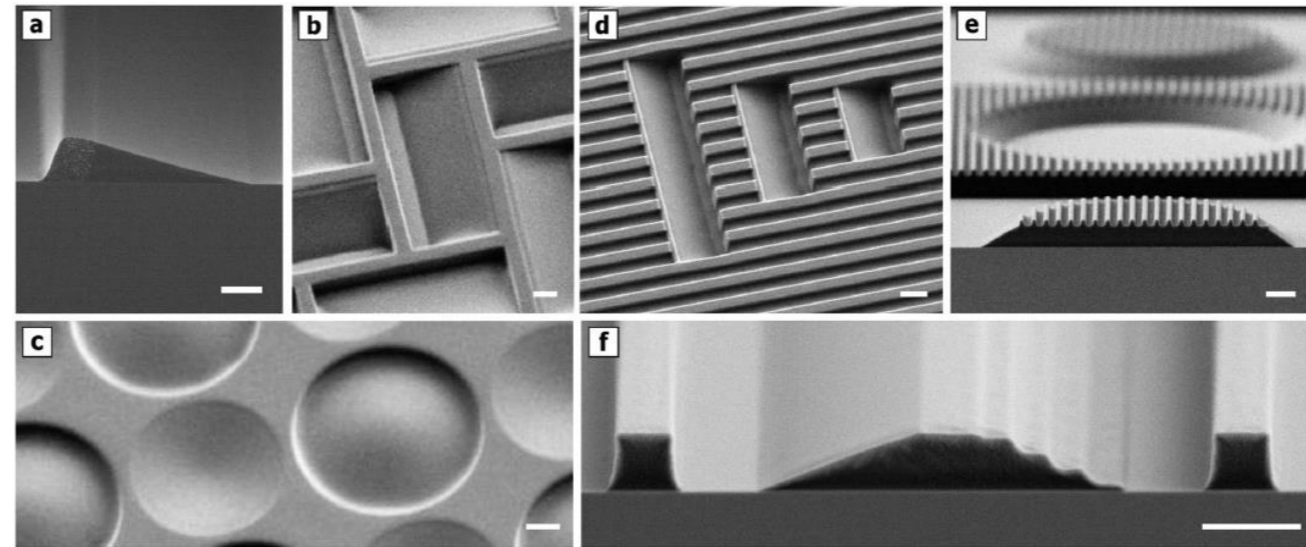
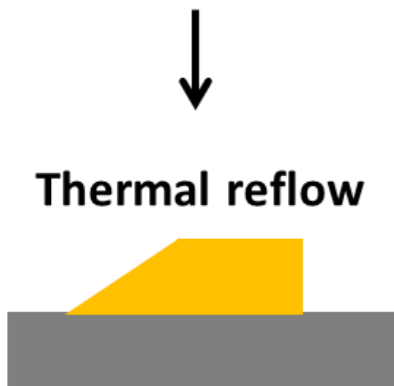
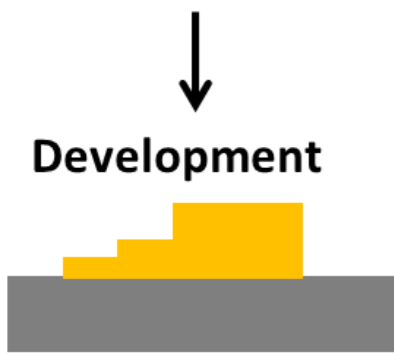
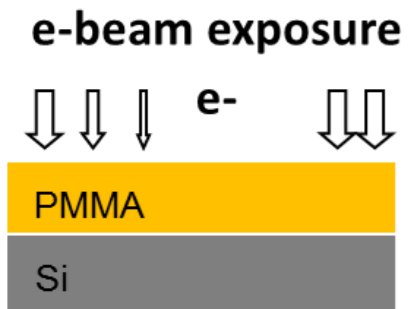
2. Lithography & Galvanofarming



4. Variothermal injection compression molding

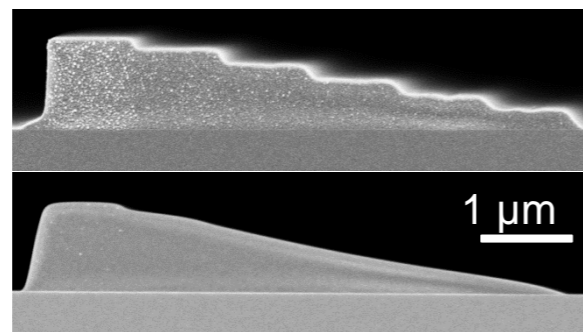
# TASTE – “Thermally activated selective topography equilibration”

Ref: A. Schleunitz et al. Nano Convergence 2014, 1:7

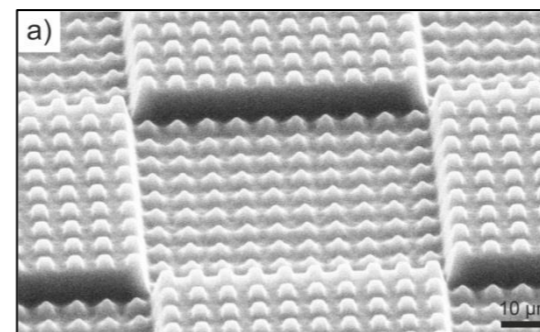


Scale bars: 1  $\mu\text{m}$

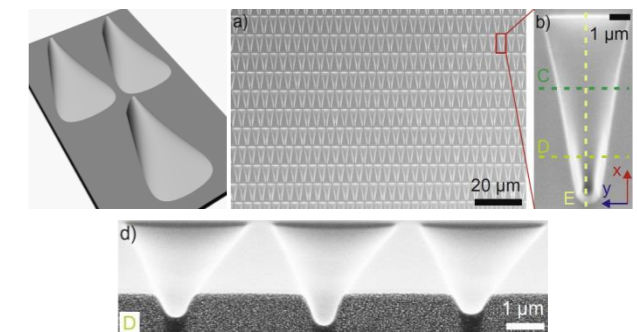
outreach into applied R&D



microprisms



hierarchical surfaces



bioinspired surfaces

Courtesy of Dr. Helmut Schiff, INKA-PSI

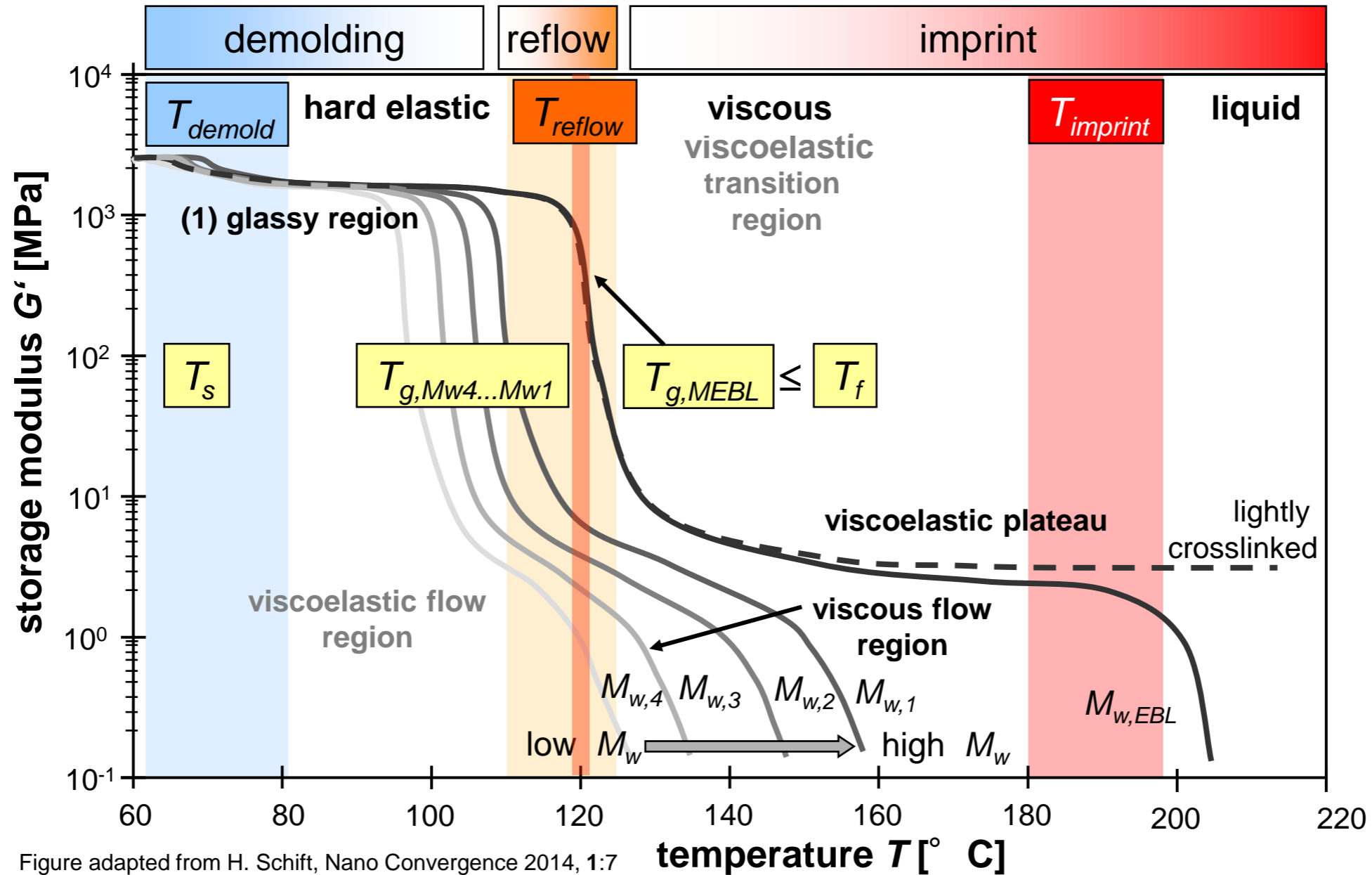


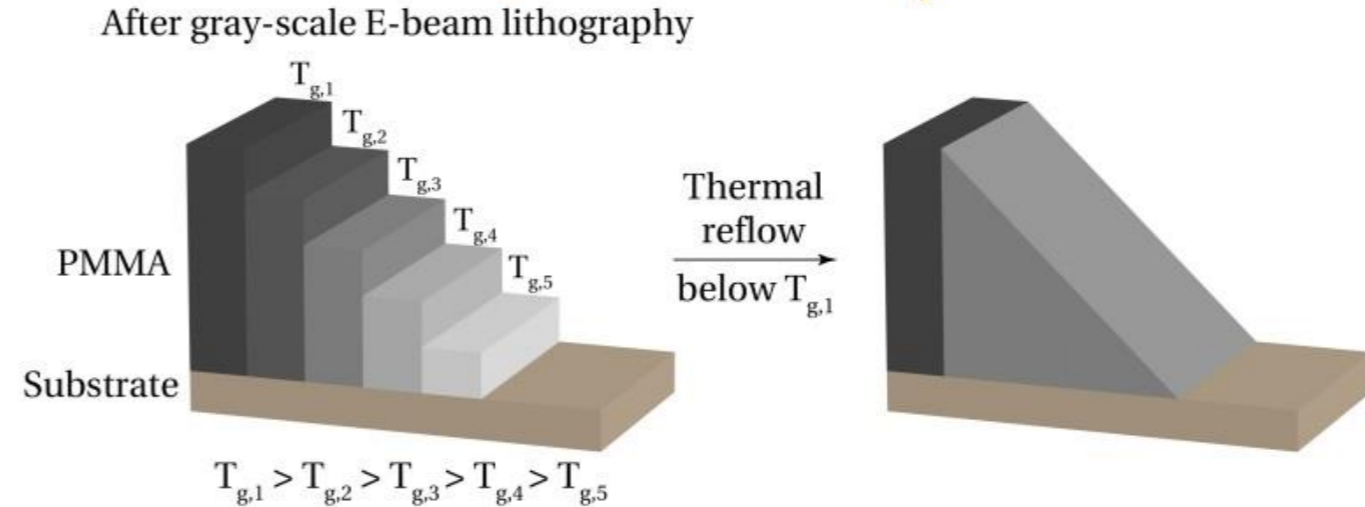
Figure adapted from H. Schiff, Nano Convergence 2014, 1:7

temperature  $T$  [° C]

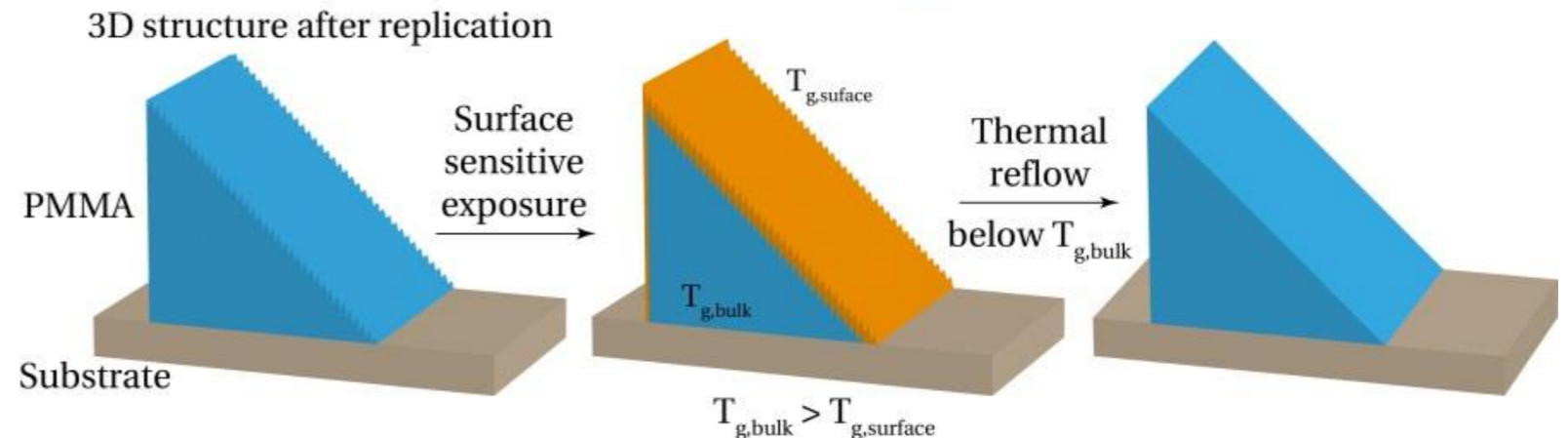
## TASTE – two variants of the same process

- «Standard» TASTE process allows manufacturing of complex 3D microstructures
- Biomimetic inspiration for new topography designs
- Selective surface smoothing can be particularly interesting for micro-optics applications...
- ... and eventually even for 3D printing

### Whole film-thickness $T_g$ contrast



### Surface selective $T_g$ contrast



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- **Perforierte Membranen für die Proteinkristallographie**
- **Zusammenfassung**

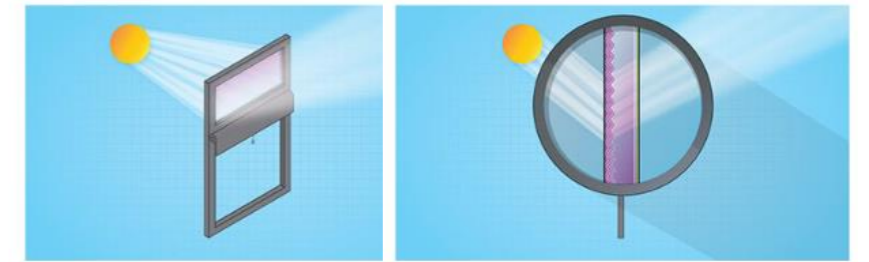
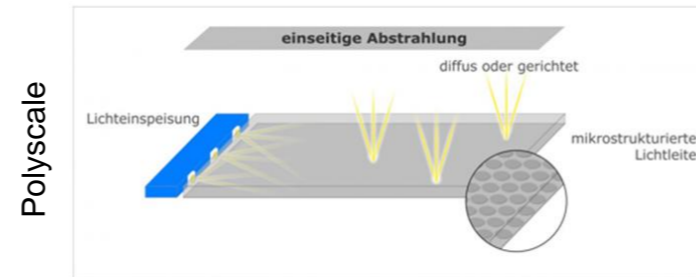
## Motivation: Advanced illumination systems

### Typical target optical performances

- **LED light diffusion**

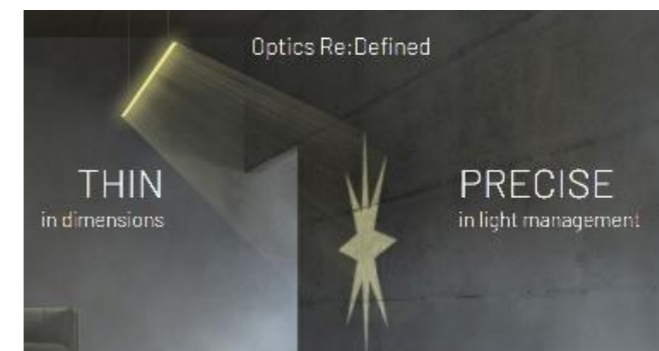


- **Light re-direction**



3M

- **Defined illumination patterns**

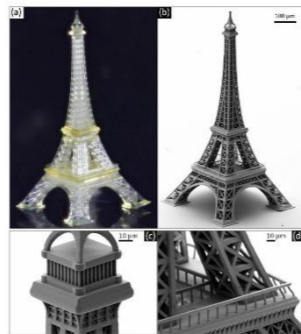
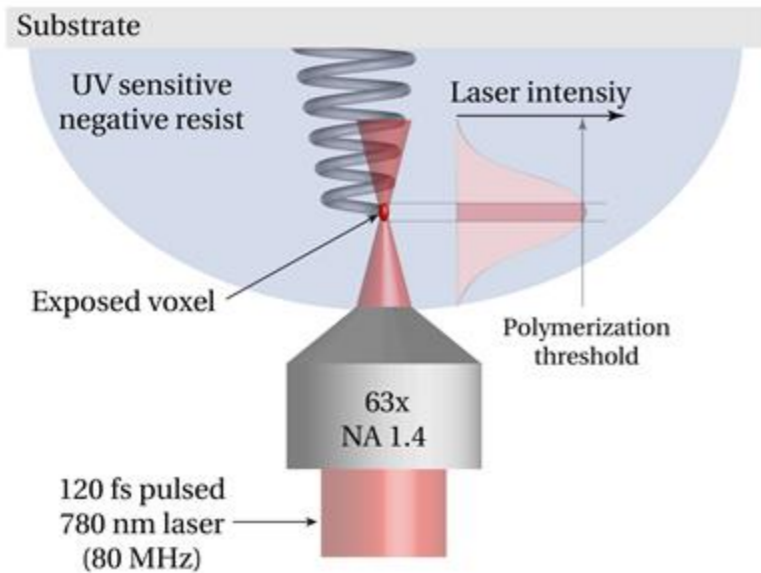


Nanoptics



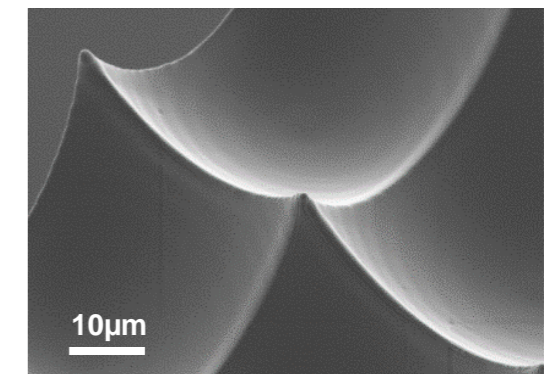
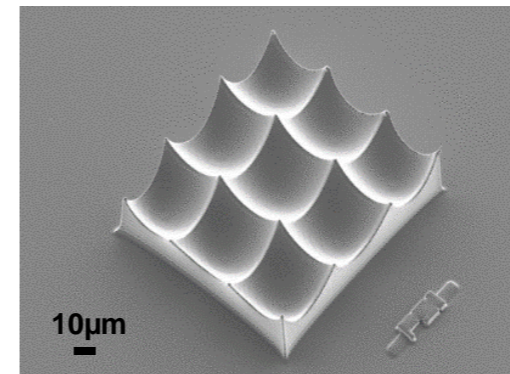
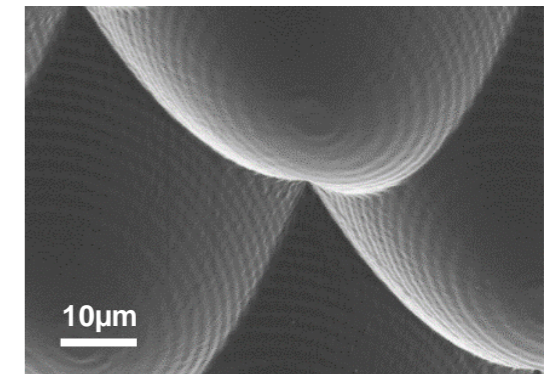
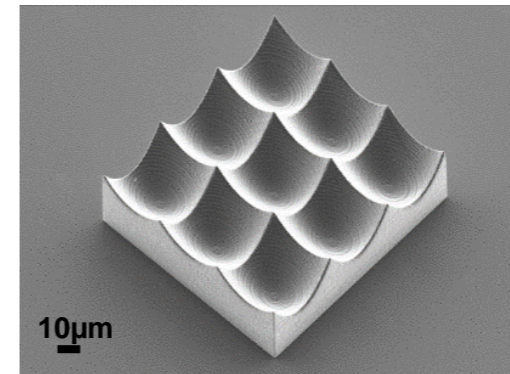
# Combining two processes with each other → advanced mastering of micro-optics

## 2-Photon Polymerization



[www.nanoscribe.de](http://www.nanoscribe.de)

## Selective surface smoothing (TASTE)

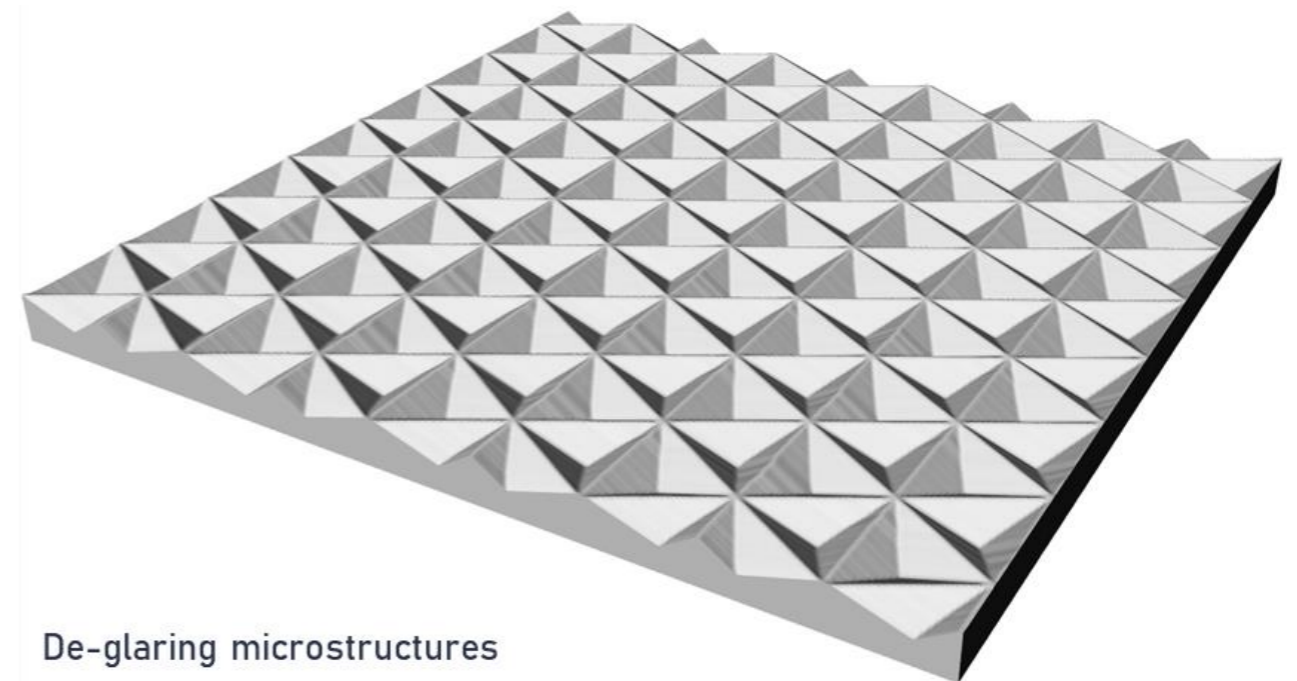
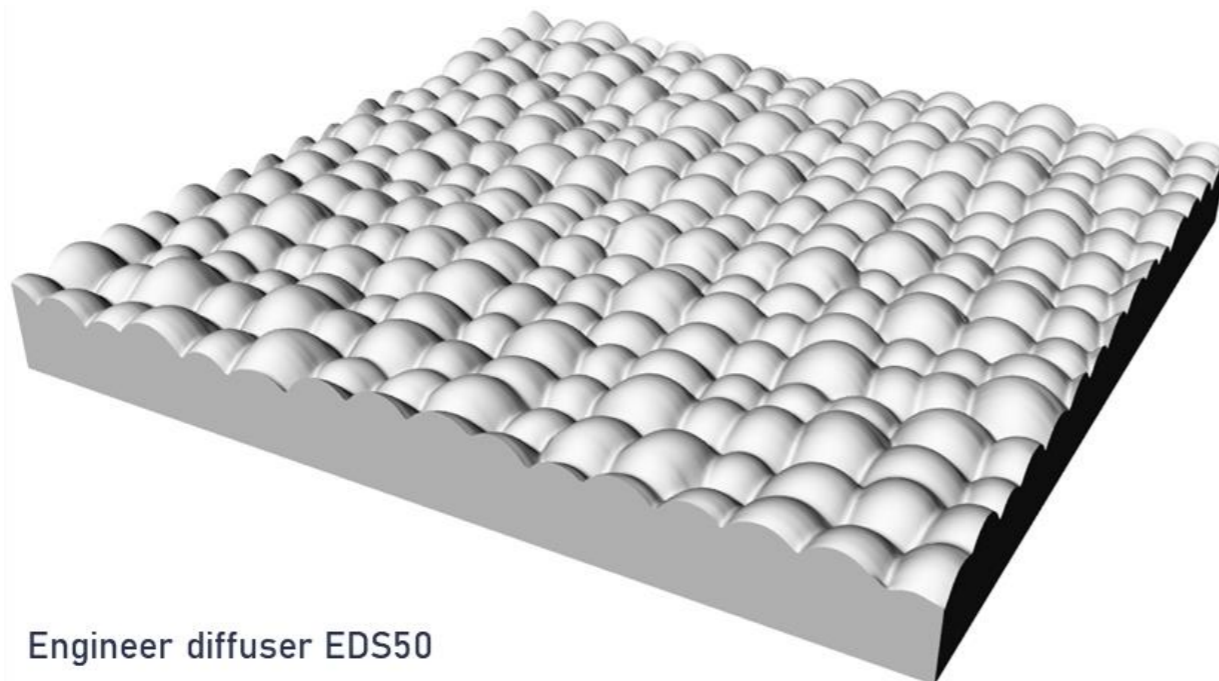


originally developed at PSI in the framework of a joint Nanoargovia project (SurfFlow)

## Two-photon polymerization – case study designs

### Two (commercial) FMLAs designs used to optimize TPP

- Engineer diffuser (round shapes)
- De-glaring microstructures (flat facets and sharp edges)



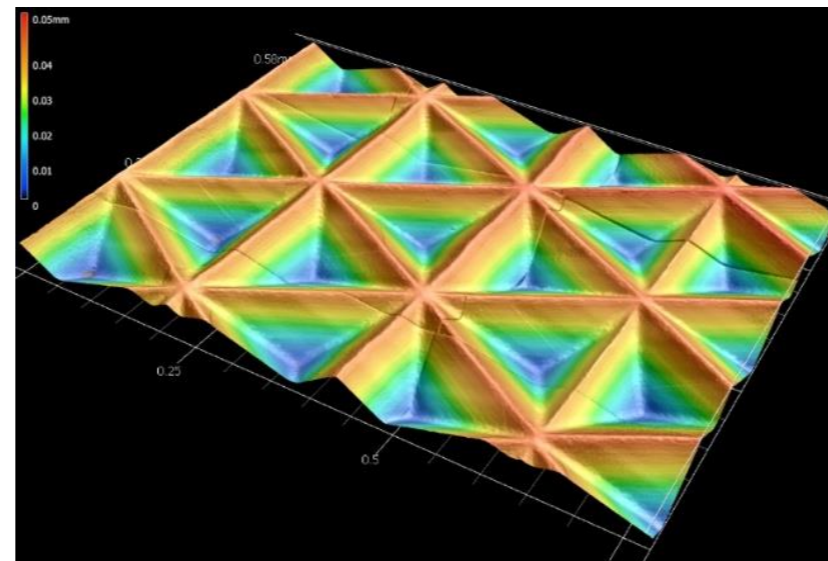
## Two-photon polymerization – process optimization

### Nanoscribe optimization with multiple test structures

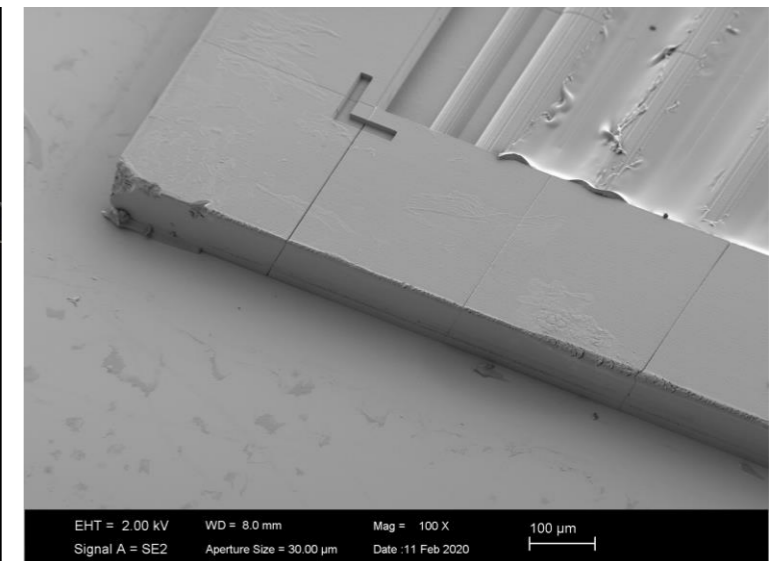
- Settings variation (power and speed) → best printing quality identified
- Different test structures → proper alignment of structures to printing direction demonstrated
- Hatching and stitching investigation → best print and surface quality identified



Parameter settings optimization  
to avoid defects

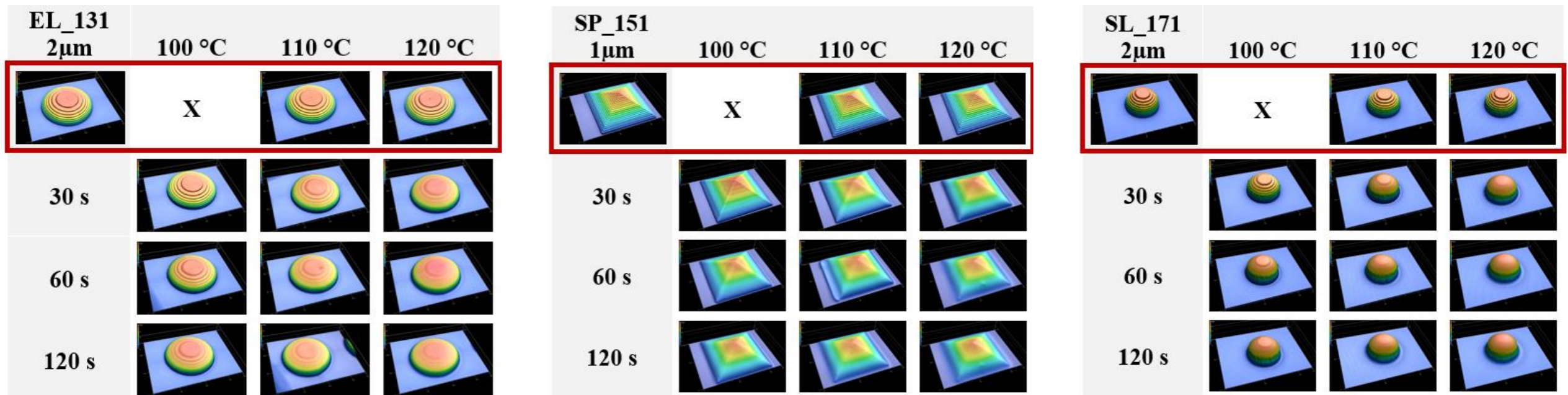


Stitching lines on different samples



## Surface smoothing by UV exposure and subsequent reflow (TASTE)

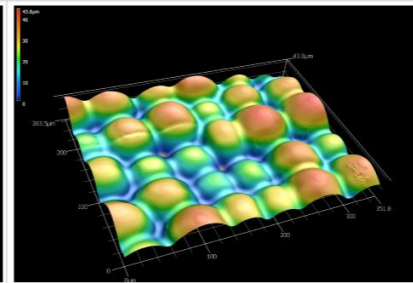
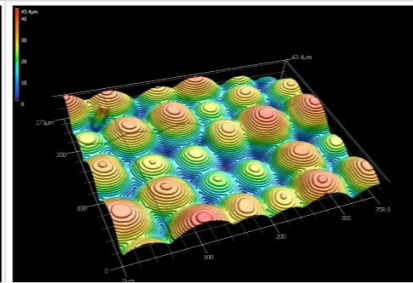
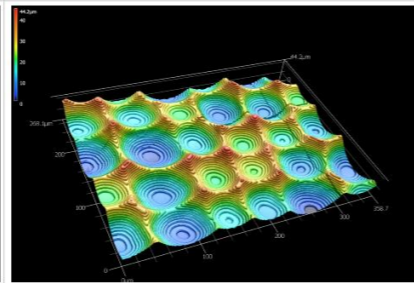
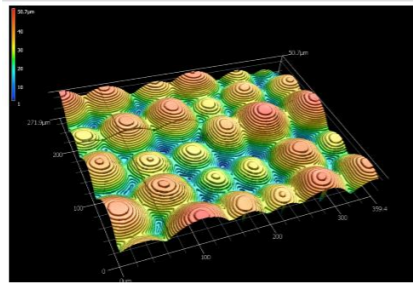
- **Test structures 2PP printed with layer heights of 1  $\mu\text{m}$  and 2  $\mu\text{m}$** 
  - Elliptical lenses (EL), square pyramids (SP), spherical lenses
- **Surface smoothing procedure**
  - Exposure to deep UV irradiation ( $\lambda = 172 \text{ nm}$ ) & subsequent thermal reflow



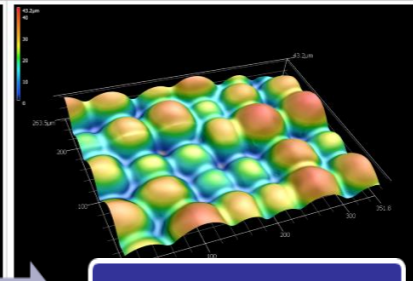
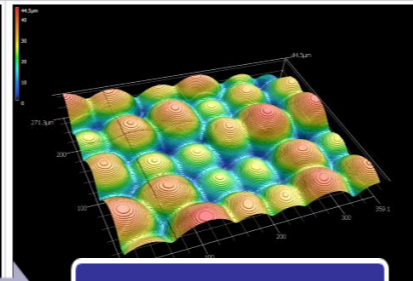
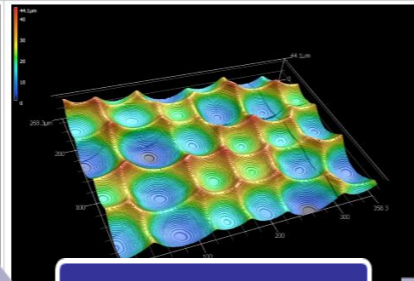
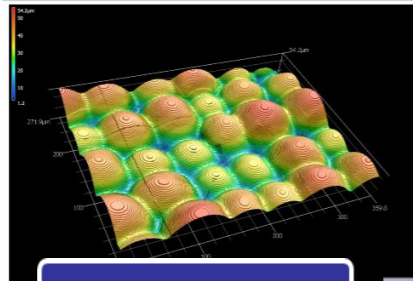
Karpik et al, *Microsystem technologies*, submitted (2021)

## Process chain validation for application designs

ED 2  $\mu\text{m}$



ED 1  $\mu\text{m}$



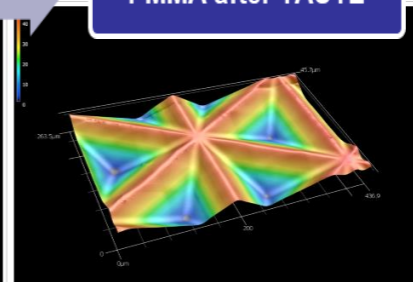
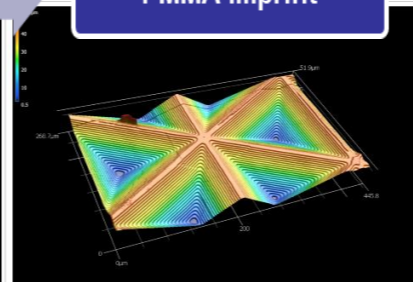
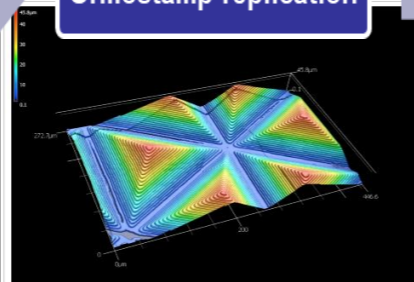
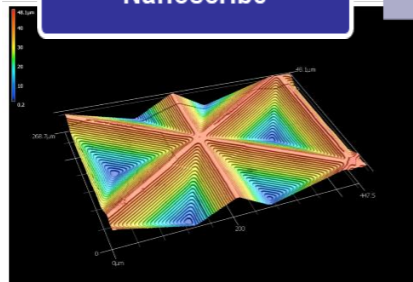
Nanoscribe

Ormostamp replication

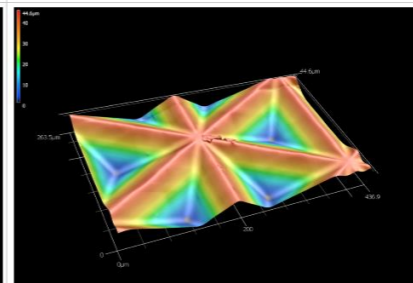
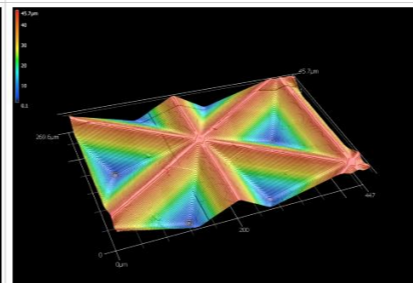
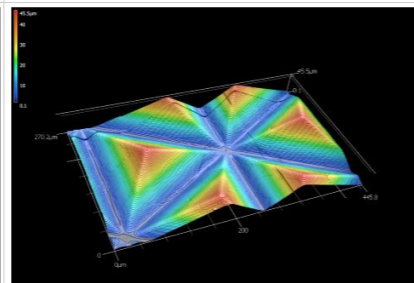
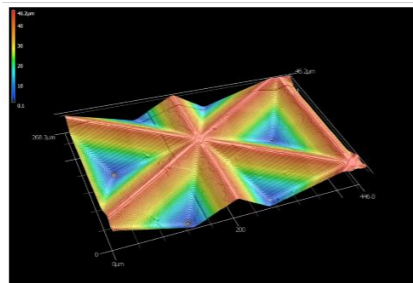
PMMA imprint

PMMA after TASTE

DG 2  $\mu\text{m}$



DG 1  $\mu\text{m}$

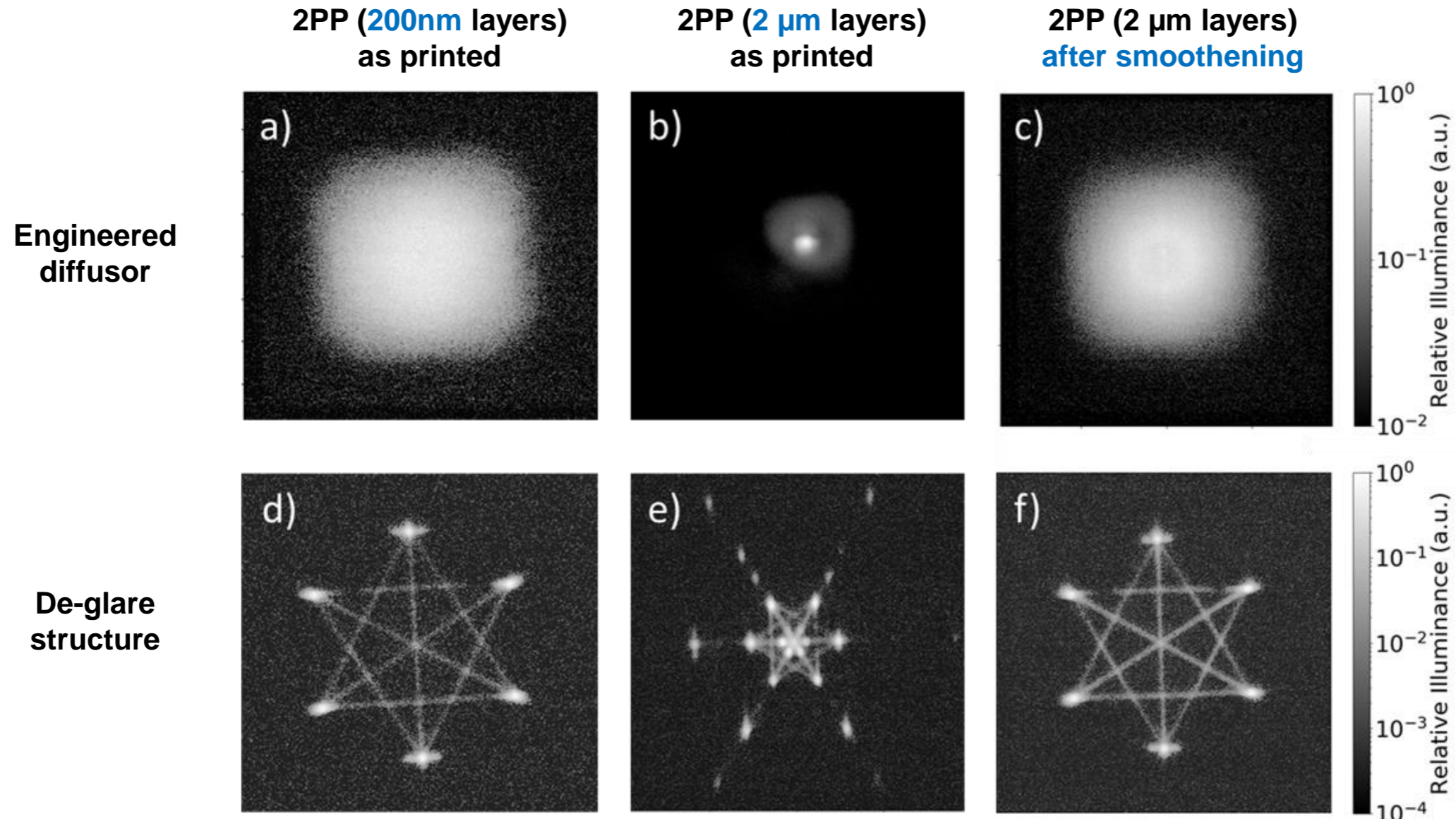


Engineered  
diffusor

De-glare  
structure

# Validation of optical performance

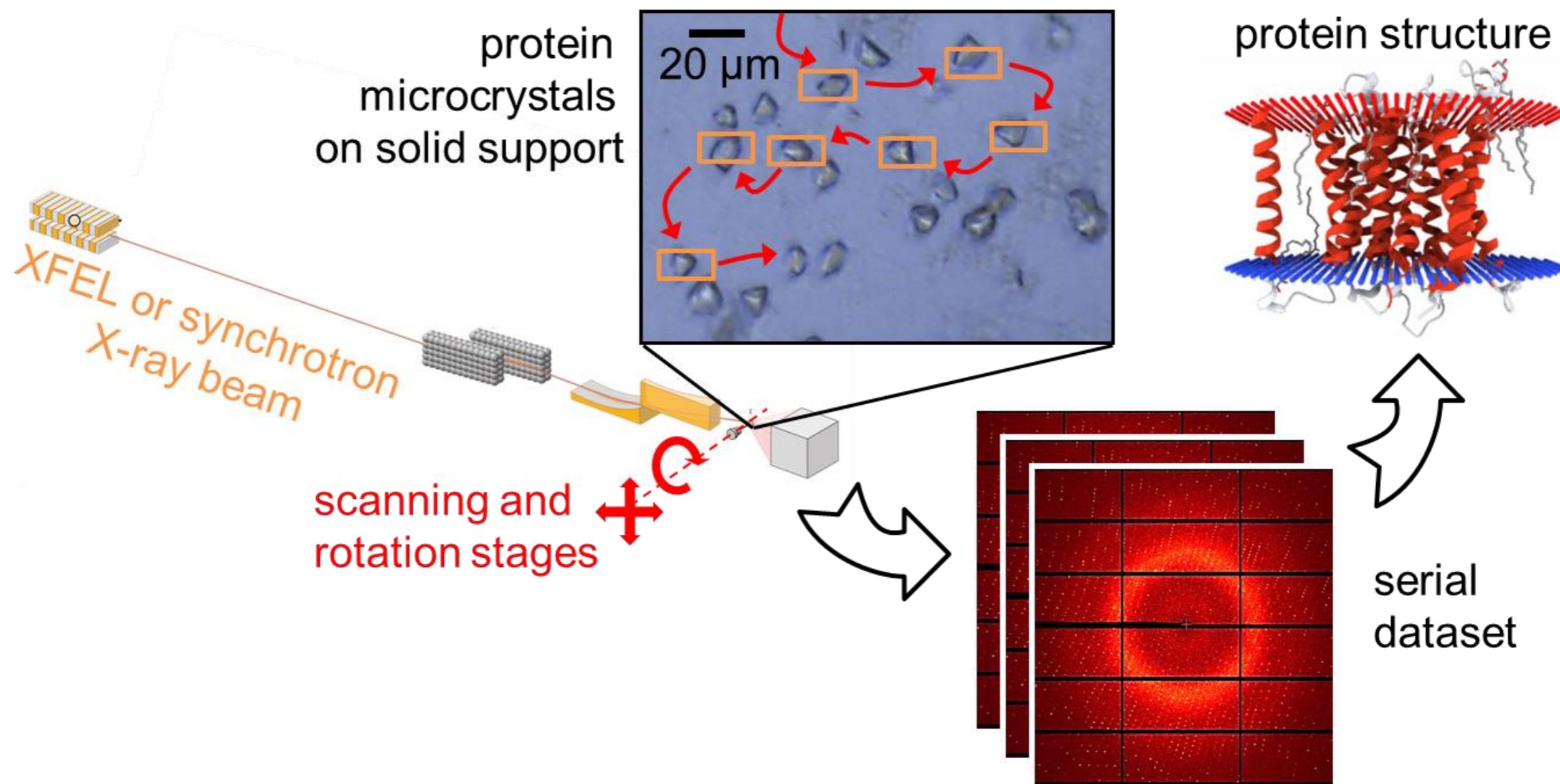
Aderneuer et al, *Optics Express* **29** (4), 5033-5042 (2021)



## Inhalte

- **INKA – ein Brückenschlag zwischen Reinraum & Technikum**
- **Industrielle Replikationstechnologien**
- **Ausgewählte Mastering-Technologien**
- **Freiform-Mikrooptiken**
- **Perforierte Membranen für die Proteinkristallographie → ein besonderes Projekt**
- **Zusammenfassung**

## Motivation: «Fixed targets» for serial protein crystallography





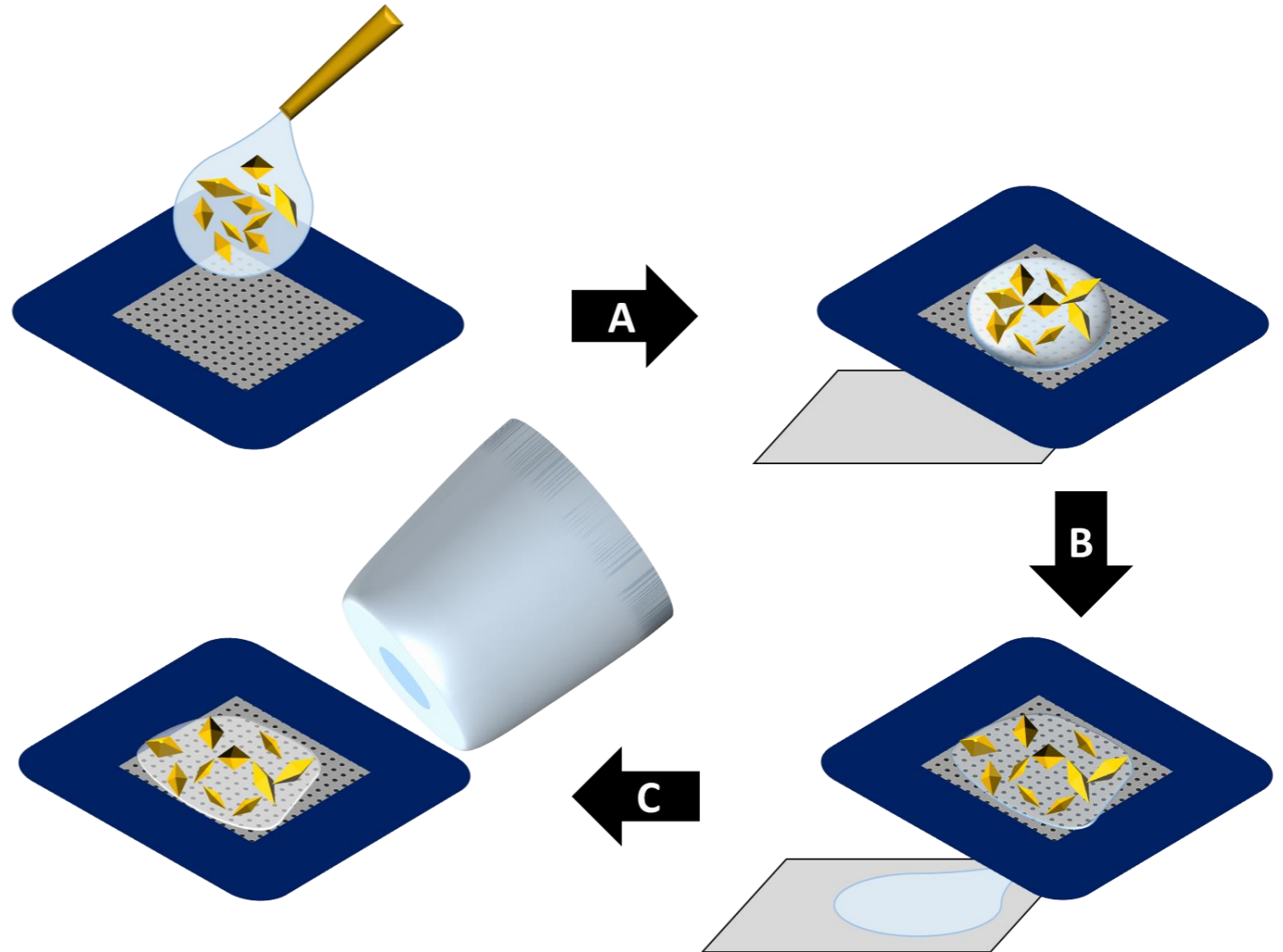
## Fixed target approach – sample preparation

### Worksteps involved

**A: deposition of protein  
crystal solution**

**B: removal of excess liquid  
with blotting paper**

**C: freezing the chip  
in a cryo-jet**



## Serial protein crystallography – how to deliver samples to the X-ray beam?

- «Gold standard» is based on Si or Si<sub>3</sub>N<sub>4</sub> membranes (few 100 nm thick)
- Some alternative solutions have been proposed...

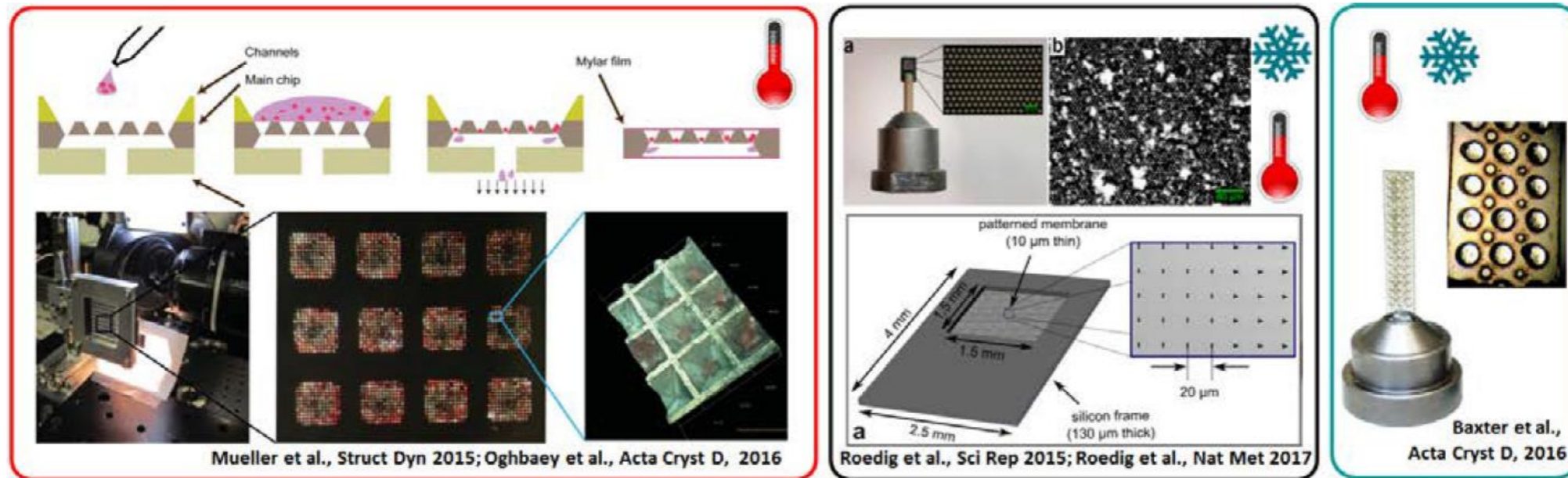
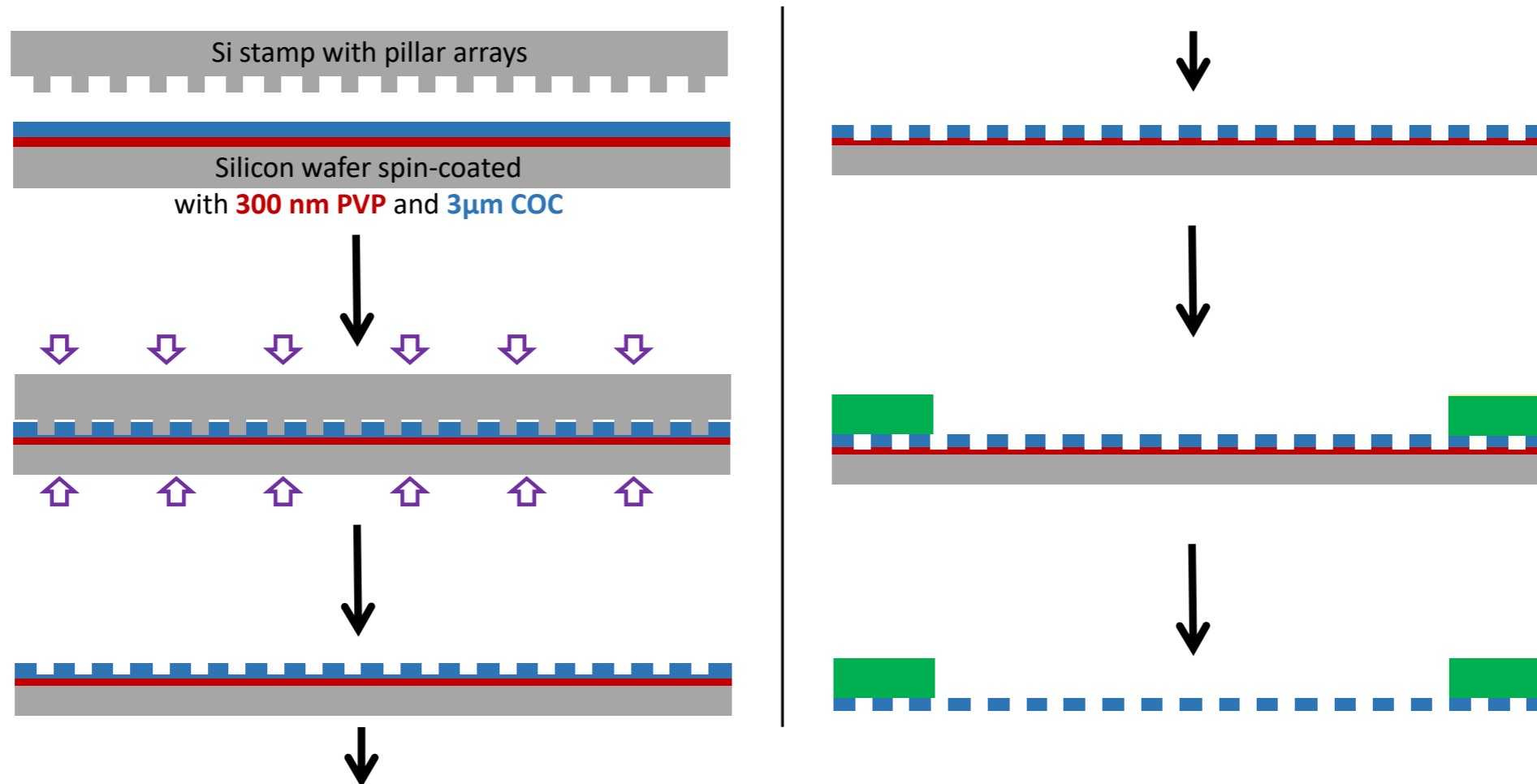


Figure 2: Examples of sample holders used for SFX, (left/middle) based on silicon microfabrication and (right) based on polymer technologies, for use at RT (thermometer) or at cryo conditions (snow flake).

**Current fixed target technologies are expensive and difficult to manufacture**

## Manufacturing scheme for suspended polymer membranes

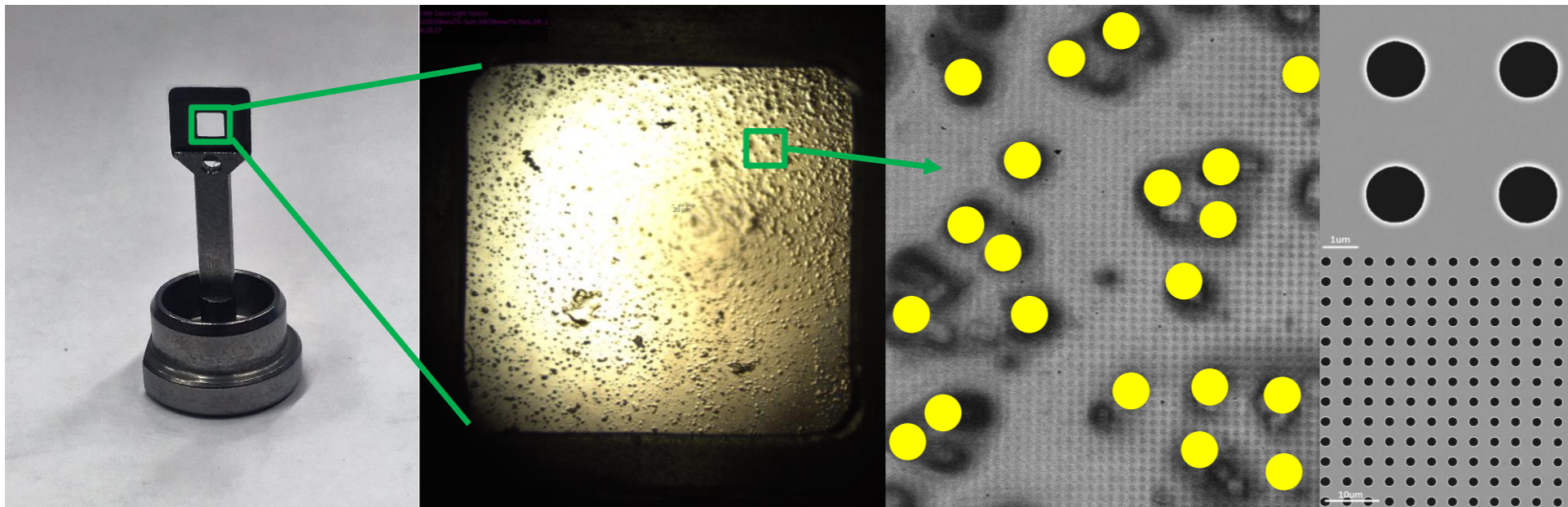
### Combining multilayer nanoimprint with additive manufacturing (here FDM)



Karpik et al, *Micro and Nano Engineering* 7 (2020), 100053

## All-polymer based fixed targets for protein crystallography

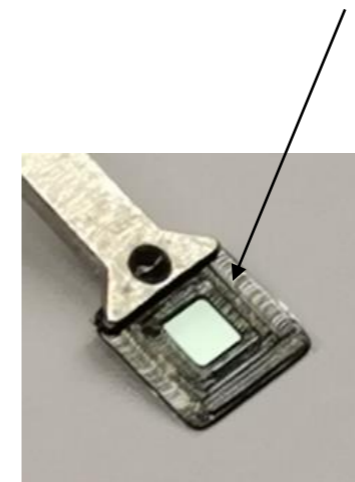
- Successfully tested during 3 commissioning beamtimes at SwissFEL
- EP patent pending
- Visualization of serial crystallography experiment → watch the yellow dots



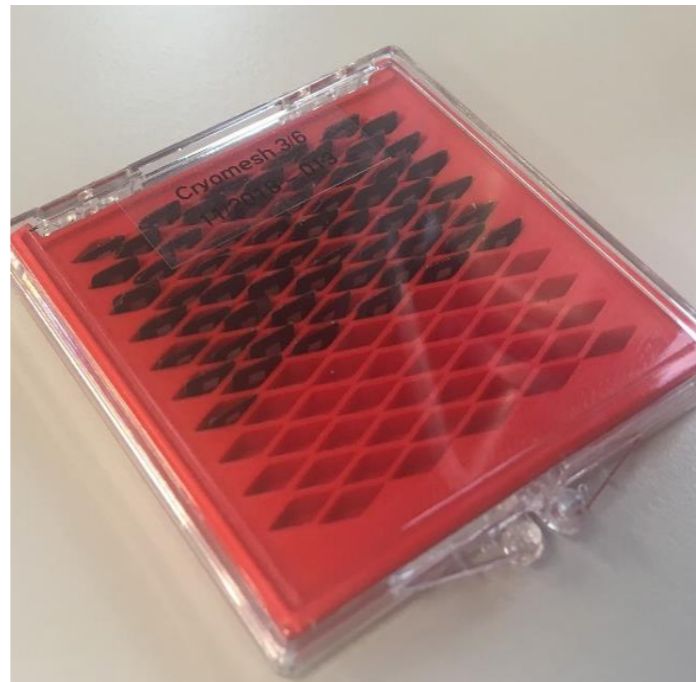
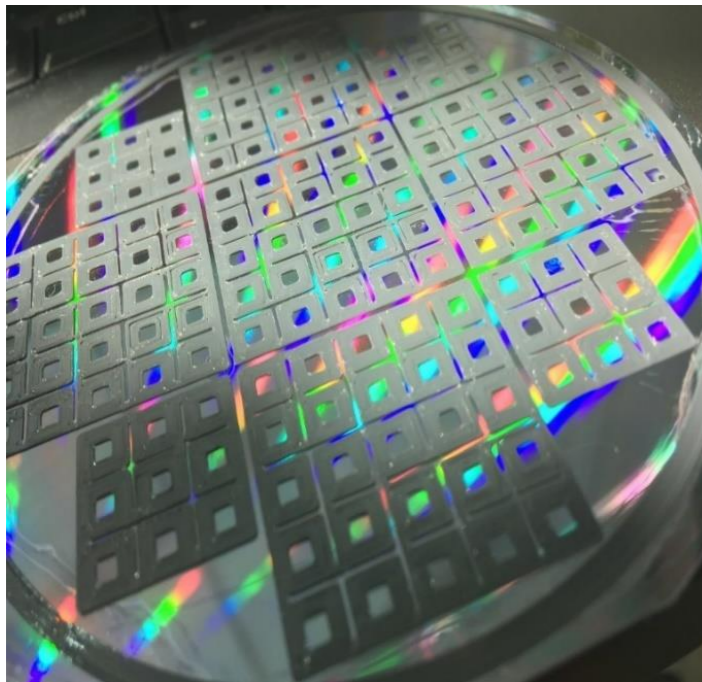
Karpik et al, *Micro and Nano Engineering* 7 (2020), 100053

## Scaling up to wafer level production

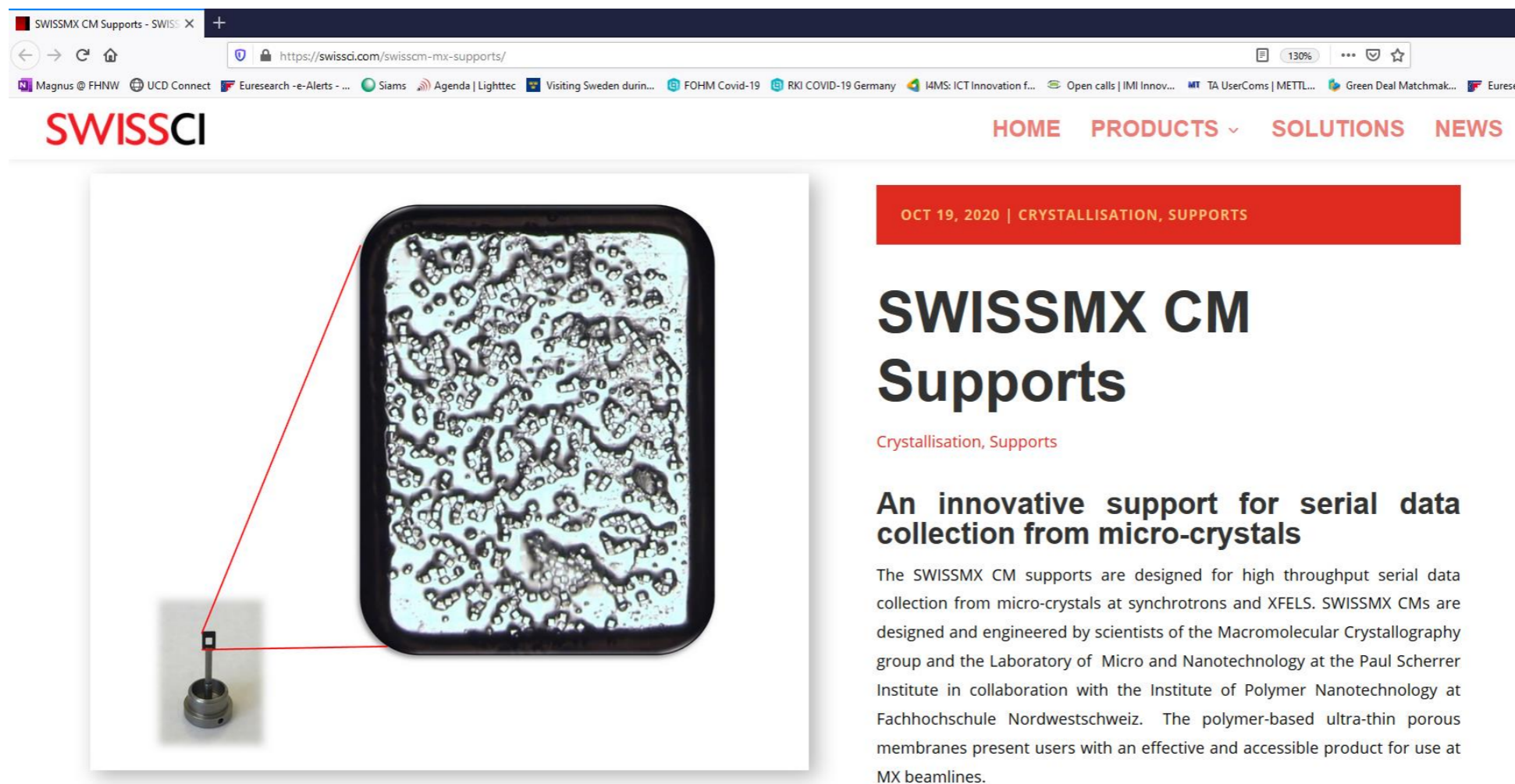
- Parallel processing, process optimization
- Supplied in dedicated «boxes»
- First customers sampled



Frame: 5x5 mm<sup>2</sup>  
Membrane: 2x2 mm<sup>2</sup>



## Crystallization supports commercialized in October 2020



**SWISSCI** HOME PRODUCTS SOLUTIONS NEWS

OCT 19, 2020 | CRYSTALLISATION, SUPPORTS

### SWISSMX CM Supports

Crystallisation, Supports

#### An innovative support for serial data collection from micro-crystals

The SWISSMX CM supports are designed for high throughput serial data collection from micro-crystals at synchrotrons and XFELs. SWISSMX CMs are designed and engineered by scientists of the Macromolecular Crystallography group and the Laboratory of Micro and Nanotechnology at the Paul Scherrer Institute in collaboration with the Institute of Polymer Nanotechnology at Fachhochschule Nordwestschweiz. The polymer-based ultra-thin porous membranes present users with an effective and accessible product for use at MX beamlines.

**Technology transfer from FHNW to PSI completed by February 2021**

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- **Perforierte Membranen für die Proteinkristallographie**
- **Zusammenfassung**

## Zusammenfassung

- **Replikation mittels industrieller Prozesse erlaubt Massenfertigung funktionaler Oberflächen**
  - Spritzgiessen / Spritzprägen im Hauptfokus → grösstes Potential für Kunststoff
  - Rollprägen erlaubt kontinuierliche Fertigung strukturierter Folien
- **Lasermikrobearbeitung wird immer besser & zunehmend wichtiger für die Werkzeugherstellung**
  - Für viele funktionale Oberflächenstrukturen durchaus genügend, aber es gibt noch viel zu tun...
- **Reinraumtechnologien ermöglichen präzise Topographien aber Integration ist anspruchsvoll**
  - Komplexe Mikrostrukturen mittels Elektronenstrahl-Lithographie (und weiteren Verfahren)
  - Mastering von Mikrooptiken mit 2-Photonen-Polymerisation
- **Kombination von Reinraum- und Kunststoff-Technologien birgt weiteres Potential**
  - Realisierung von unkonventionellen Bauteilen, Produkten und Prozessen

**Gerne diskutieren wir mit Ihnen Möglichkeiten & Grenzen zur Funktionalisierung Ihrer Kunststoffoberflächen...**



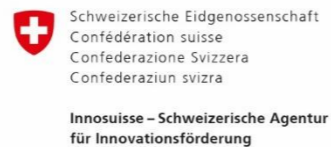
## Acknowledgements

- **INKA-FHNW:** Jerome Werder, Michael Grob, Mischa Wälty, Laurent Feuz
- **IPPE-FHNW:** Marco Guilherme, Pascal Vollenweider, Ronald Holtz
- **FHNW Alumni:** Agnieszka Karpik, Sebastian Wollmann, Maximilian Marhöfer, Jonathan Schmidli
- **PSI:** Celestino Padeste, Konrad Vogelsang, Helmut Schiff
- **CSEM:** Tamara Aderneuer, Oscar Fernandez, Rolando Ferrini
- **BFH:** Stefan Remund, Beat Neuenschwander

- **Selected project partners:**



- **Funding:**



**Danke für Ihre Aufmerksamkeit !!**



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