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PSI

Jens Gobrecht :: Leiter, Labor Mikro- und Nanotechnologie :: Paul Scherrer Institut

Additives Manufacturing für optische 3D-Mikrostrukturen

Trends in Micro Nano, 1. Sept. 2016, Buchs SG

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Inhalt

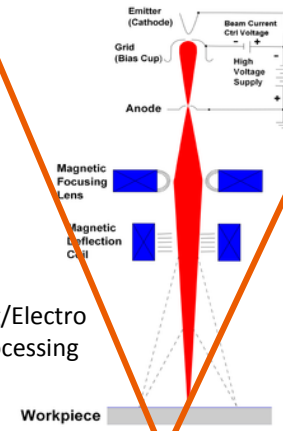
- Motivation
- Additive manufacturing im (sub-)Mikrometerbereich
- Problem Oberflächenrauhigkeit und Reflow-Verfahren
- Beispiele
- Zusammenfassung

Motivation

- Mikrooptische Strukturen (Linsen, Prismen, Gitter, Wellenleiter oder Kombinationen davon) finden immer Zahlreichere Anwendungen.
- Transparente Kunststoffe bieten sich aufgrund günstiger Kosten und guter Verarbeitbarkeit als Materialien an.
- Additive Fertigungsverfahren («3-D-Druck») stehen heute auch für diese Materialien und den Submikrometerbereich zur Verfügung
- Häufig genügt jedoch die Oberflächenqualität noch nicht den Anforderungen in der Optik

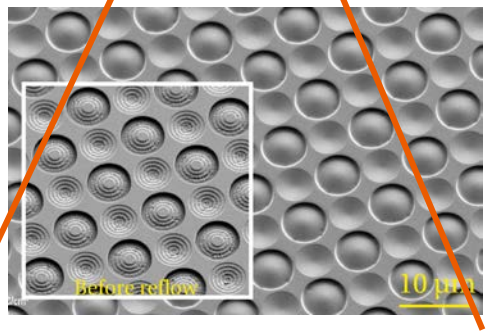
Fabrication techniques for “3D structures”

E-beam lithography

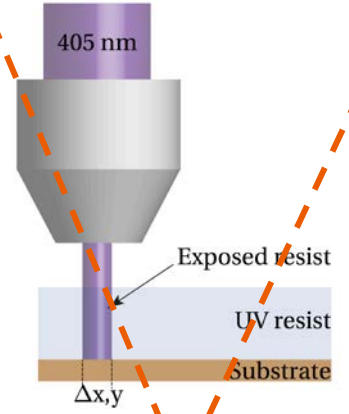


wikipedia.org/Electron_beam_processing

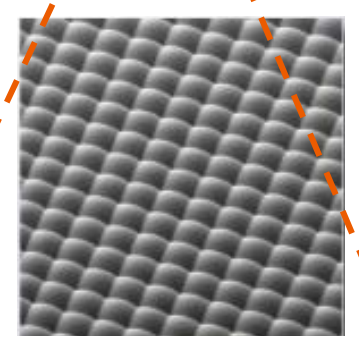
- Very high resolution
- Good stitching
- Long writing times
- Tall features not possible
- Charging effects



Direct Laser Exposure

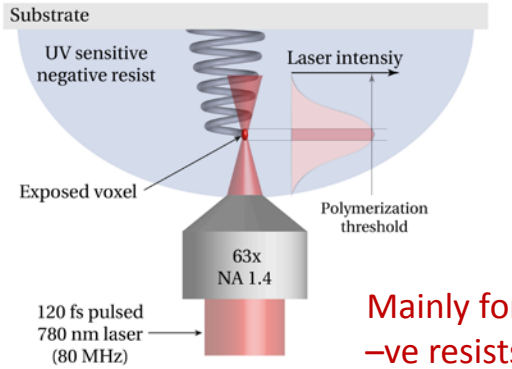


- OK resolution
- Good stitching
- Fast writing times
- Tall features not possible
- No substrate effect



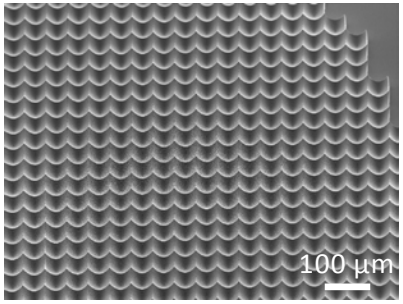
MLA, 20 µm height, 100 µm pitch

2 photon polymerization

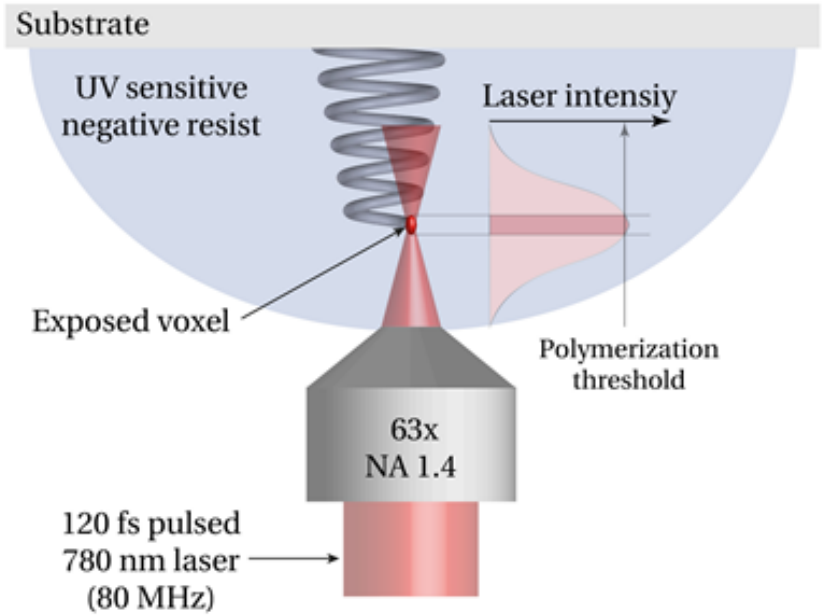


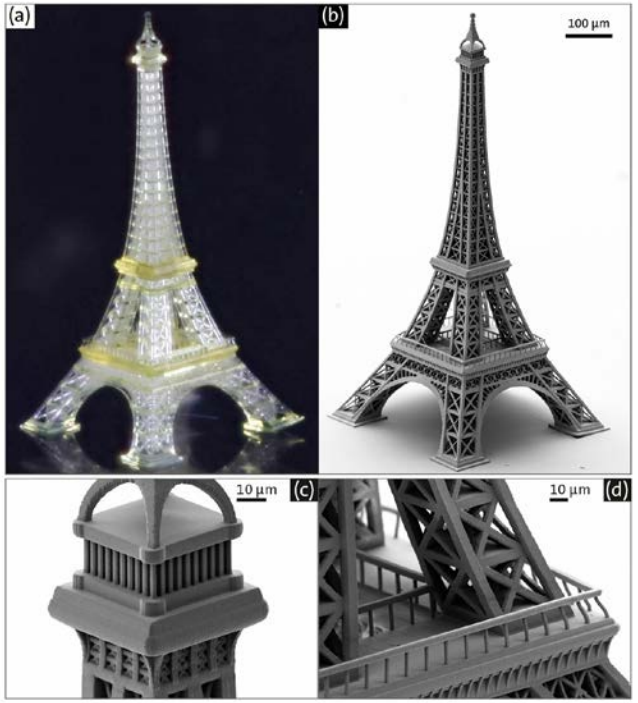
Mainly for –ve resists

- Good resolution
- Good stitching
- Very slow writing times
- Tall features possible
- No substrate effect

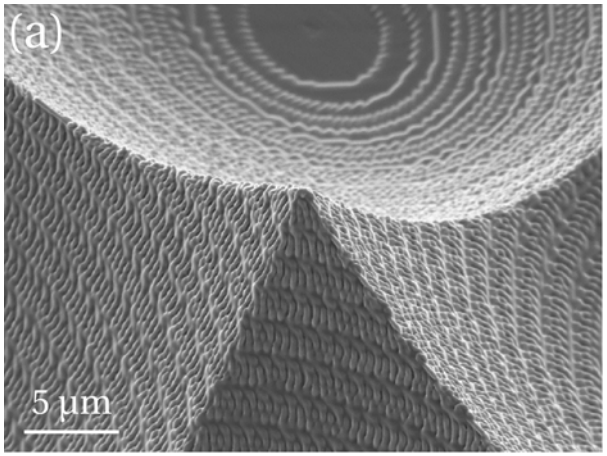


2 Photon Polymerization Technique





Surface roughness
may be a problem
in optical applications

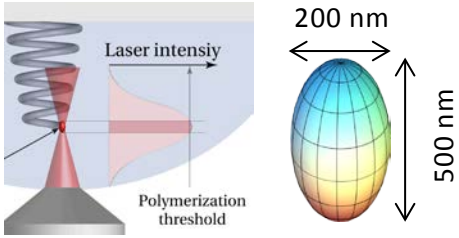


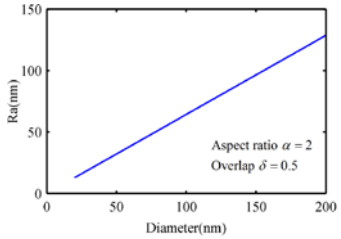
www.nanoscribe.de

But.... Roughness concern in 2PP

Voxel size

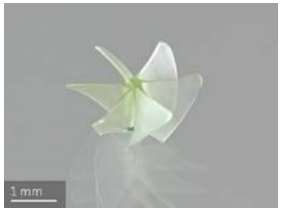
- Polymerization threshold and laser dose





- Long writing times
- Very small head room
- Increasing voxel size???
- No shape change

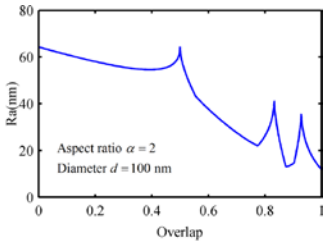
IPS resist, photo initiator diffusion higher

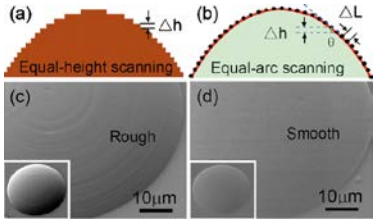


X. Zhou AIP Adv 2015

Writing strategies

- Increasing the voxel overlap
- Variable height slicing
- Arc scanning



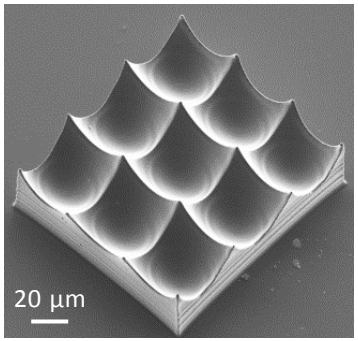


- Long writing times
- Limited process window
- Shifting from Δz to Δx
- No shape change

D. Wu APL 2010

Post processing

- Reflow of resist
- Replication might be required



- Short writing time
- Huge process window
- Tricky for undercuts & side walls

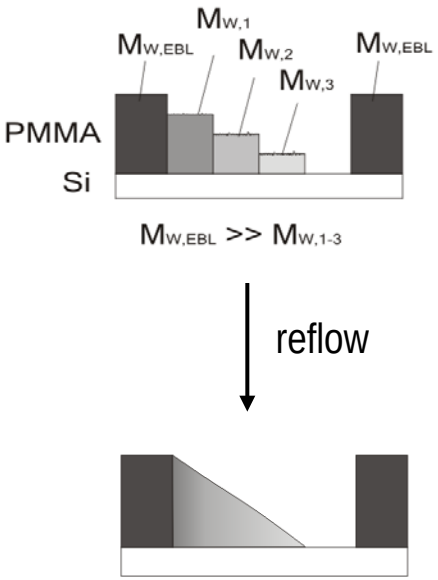
X. Zhou AIP Adv 2015

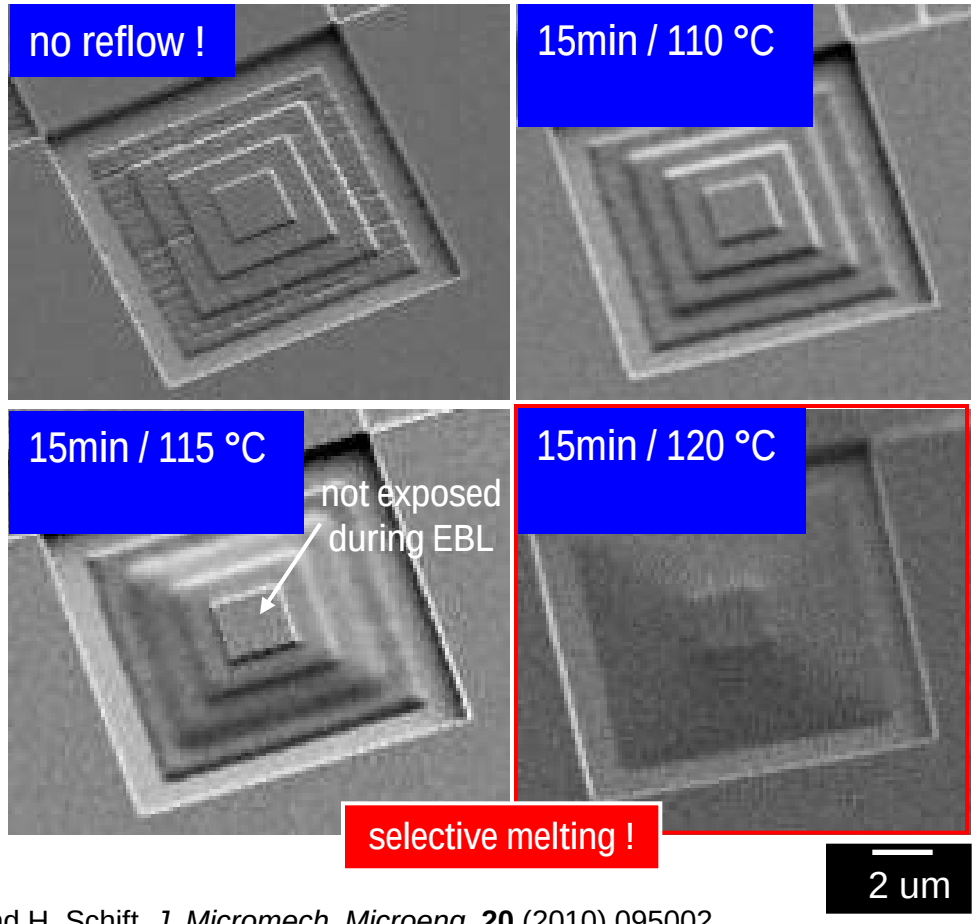
Application Example: Microoptics

Mastering Technology: Thermal post-processing of 3-D resist pattern

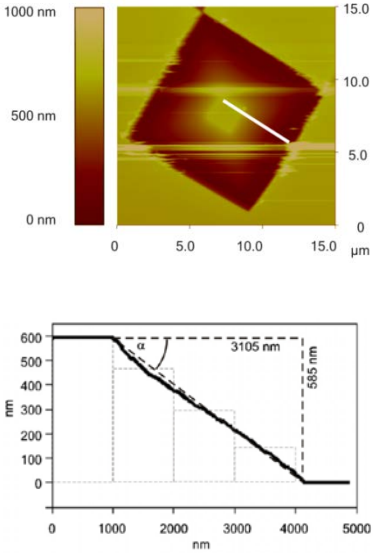
PMMA resist layer (500 nm high) after development

resist pattern / molecular weights





AFM analysis



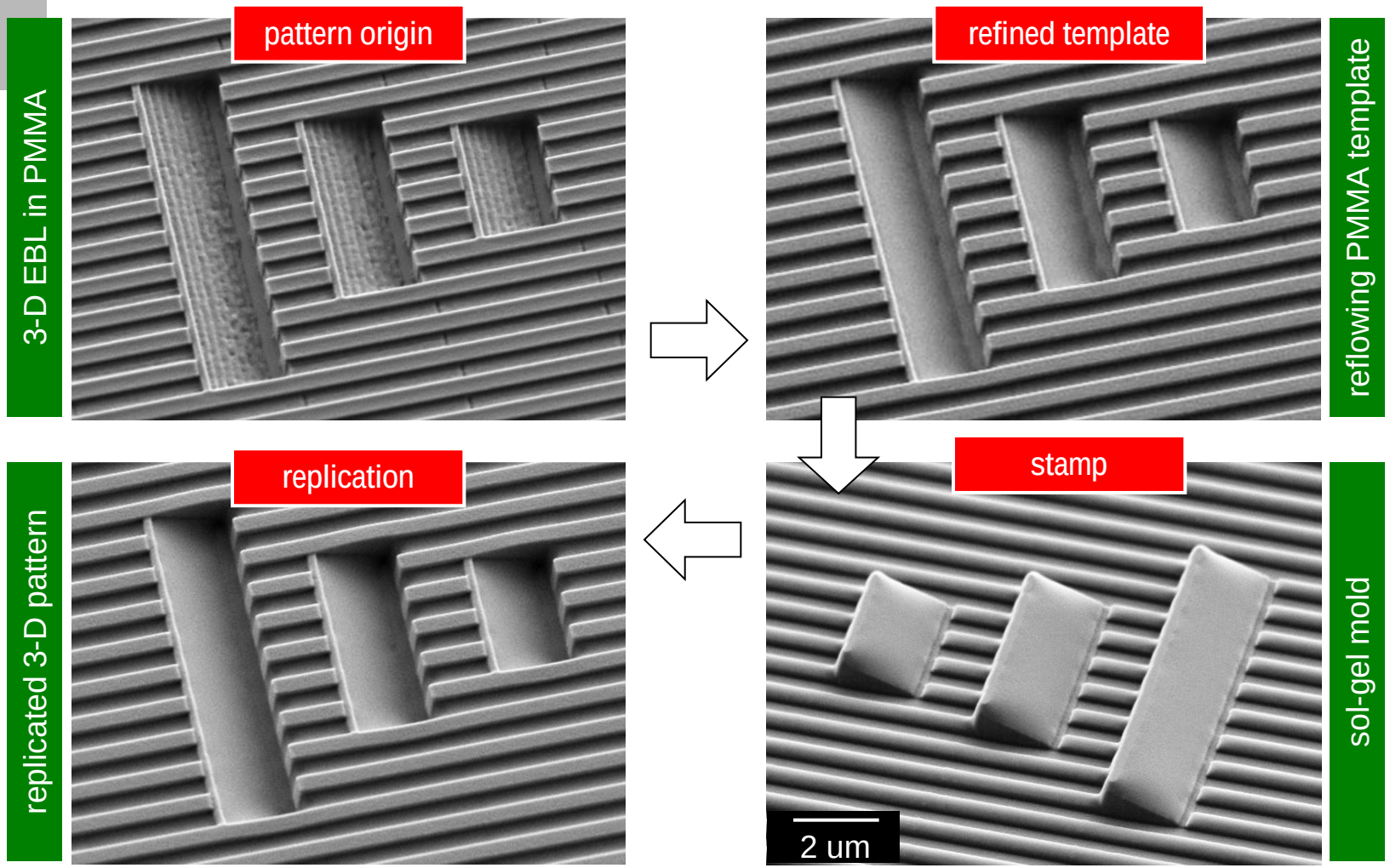
slope inclination ~ 11 °

Reference: A. Schleunitz and H. Schift, *J. Micromech. Microeng.* **20** (2010) 095002.

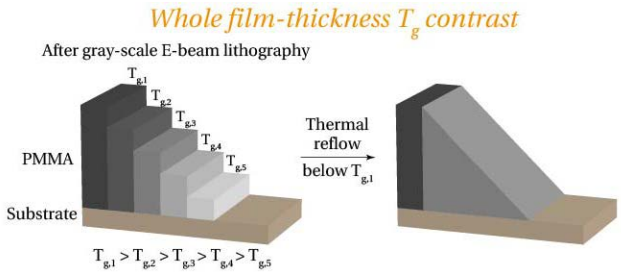
Courtesy of A. Schleunitz, INKA-PSI

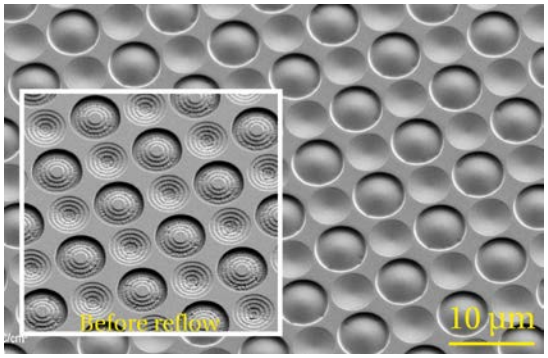
Mass replication using nanoimprint lithography (NIL)

Pattern are copied into a sol-gel material and repeatedly replicated into a polymer

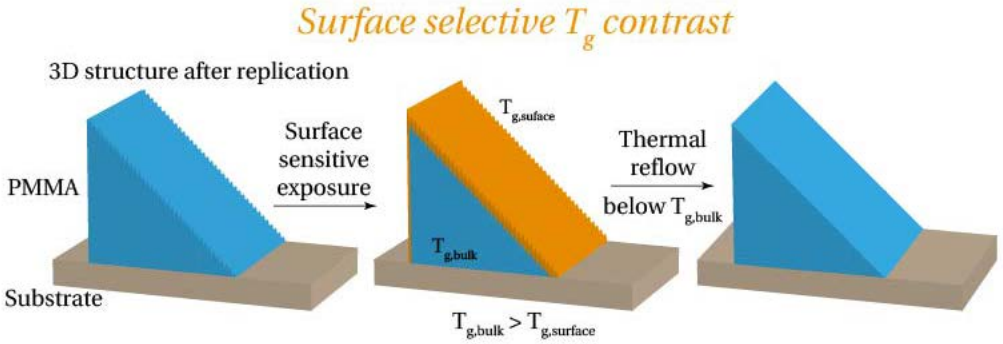


Surface sensitive damage



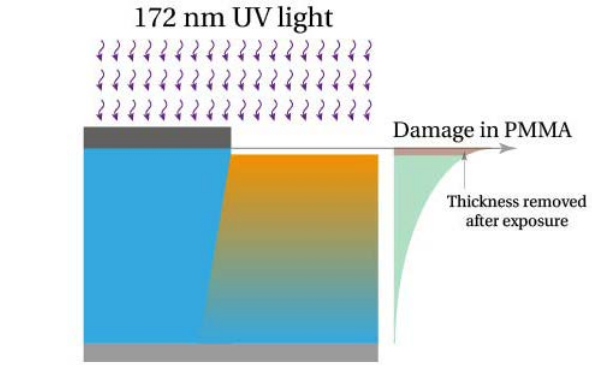


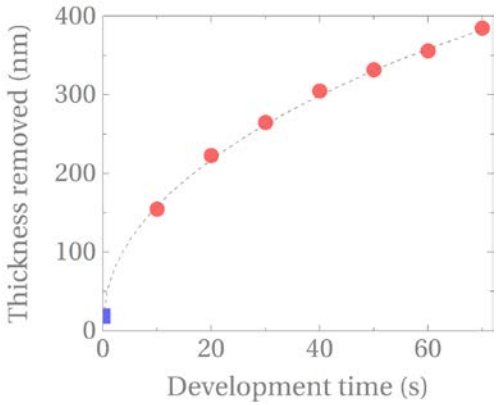
A. Schleunitz NC 2014

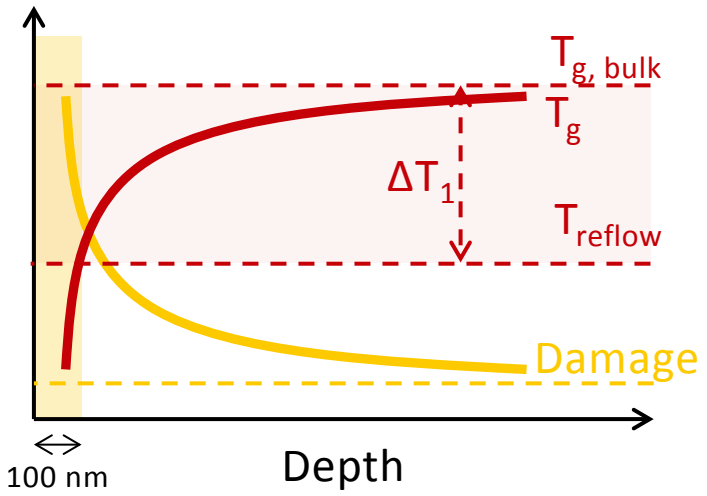


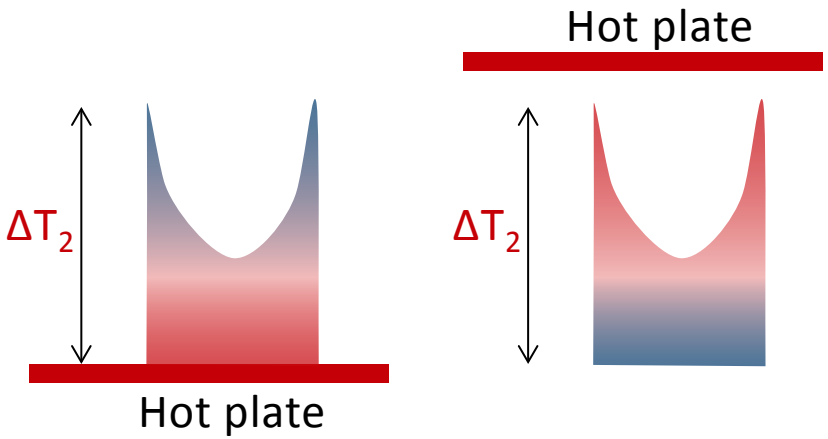
High energy E-beam	Ion beam (O_2 or Ar plasma)	285 nm UV Ozone	172 nm VUV	13.6 nm EUV	1 nm Soft X-Rays
High damage	Etching technique	Larger penetration depths	Reasonable penetration (100-200 nm)	Small penetration (100 nm)	Large penetration (100 µm)
Ambient conditions	Vacuum process	Ambient conditions	Ambient conditions	Vacuum process	Ambient conditions
Low energy E-beam				Expensive	
Tedious/Vacuum					

Surface sensitive damage: Process window



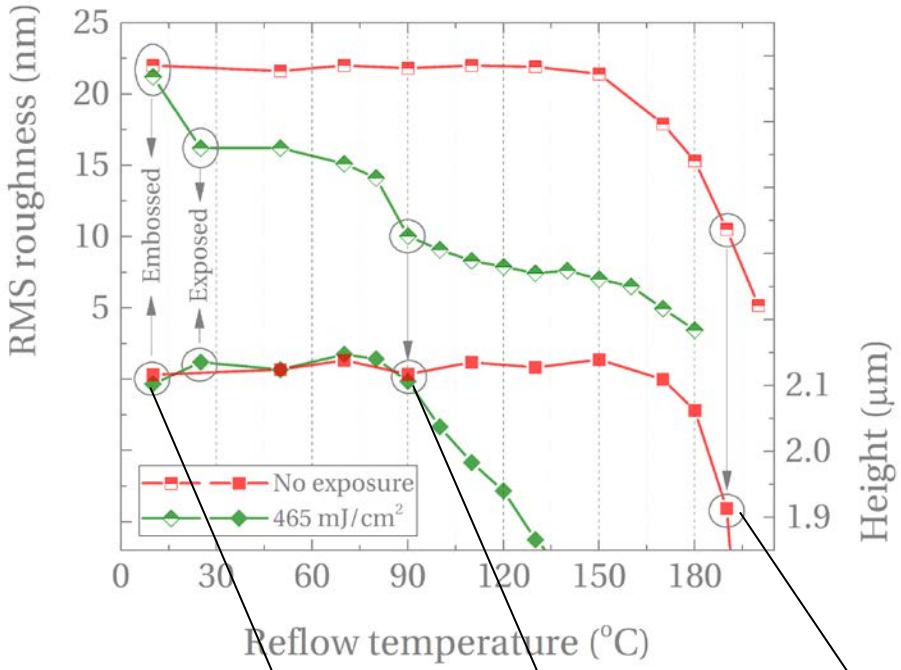




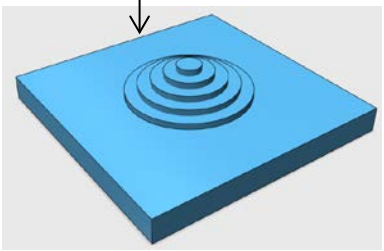


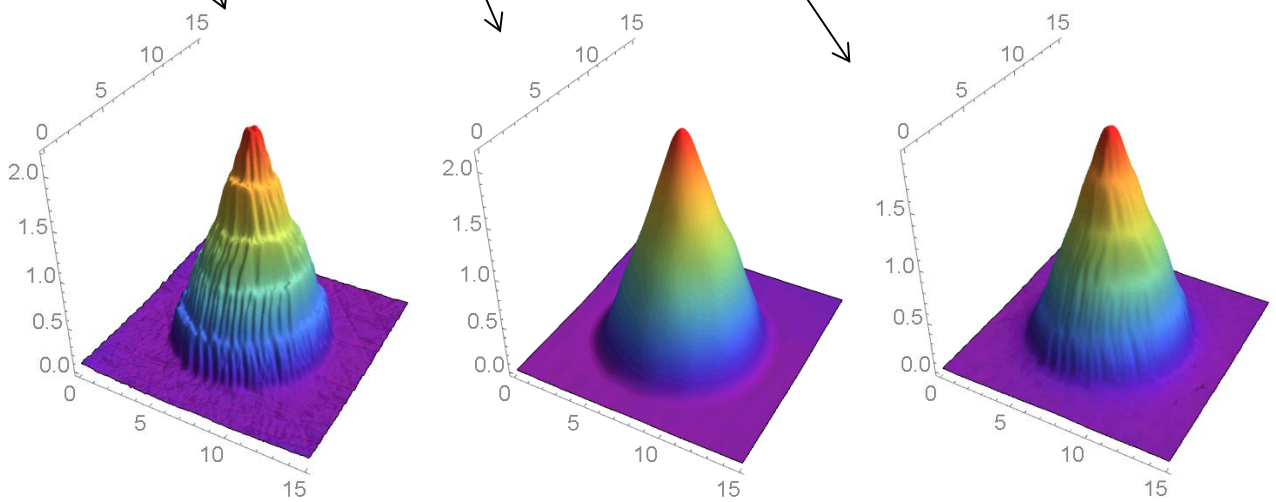
Process latitude = $\Delta T_1 - \Delta T_2$

Smoothening: exposed & reflow (PMMA)

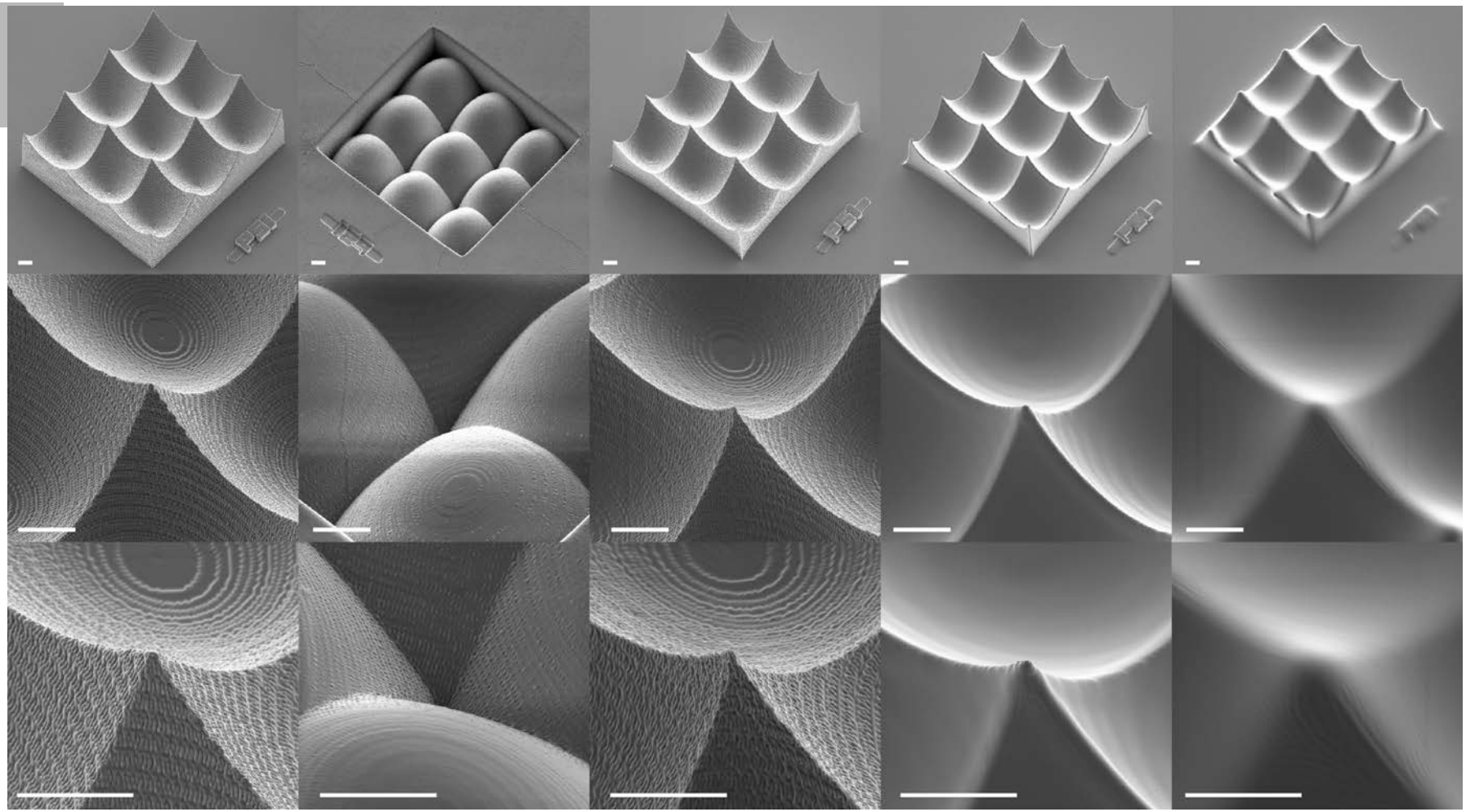


2 μm tall AFM test structures were transferred for roughness measurement



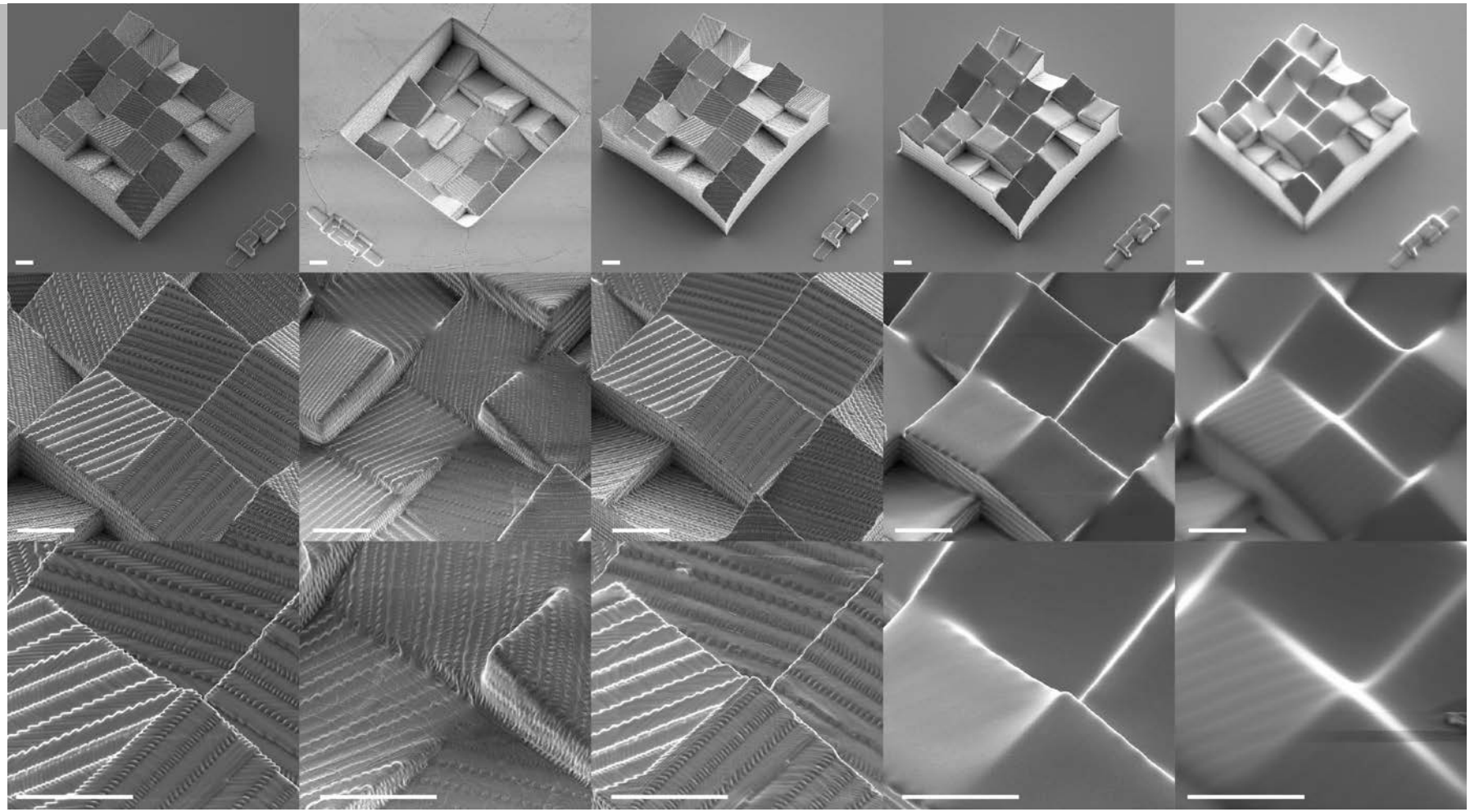


Application example: Micro lens array



Scale = 10 µm

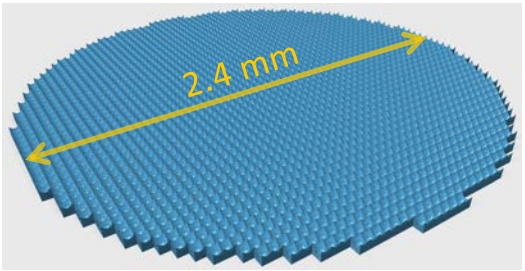
Application example II: Micro prism array

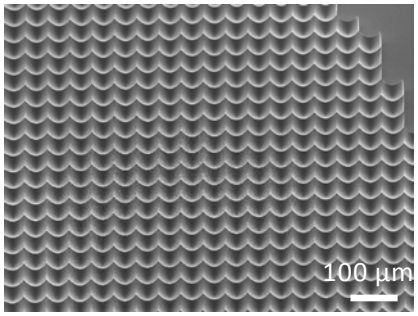


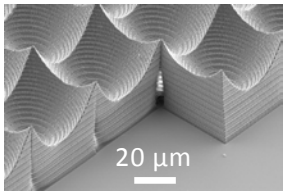
Scale = 10 µm

Microlens-array device (48 hours writing)

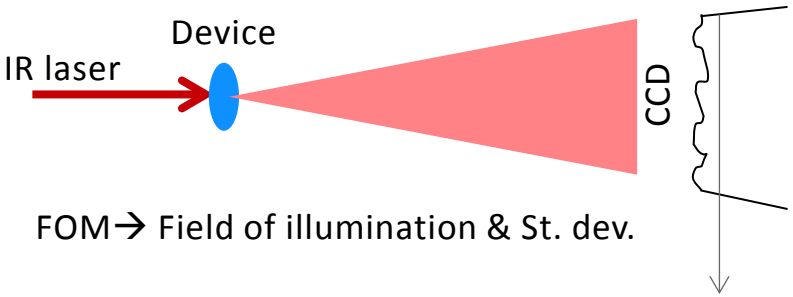
Master fabrication



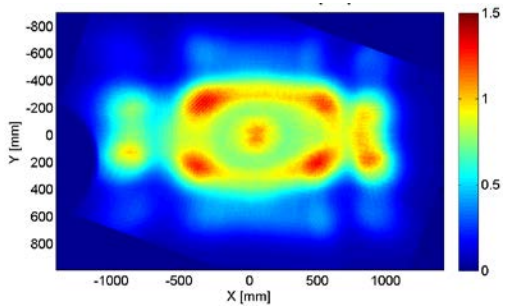




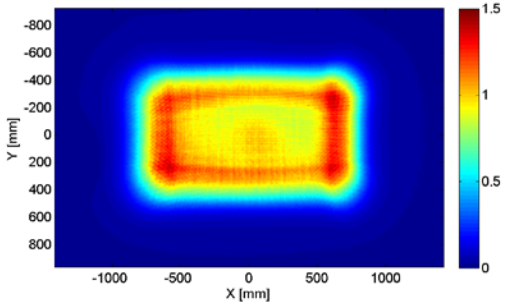
Optical measurement setup



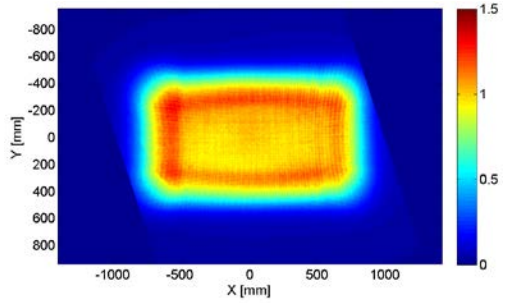
FOM→ Field of illumination & St. dev.



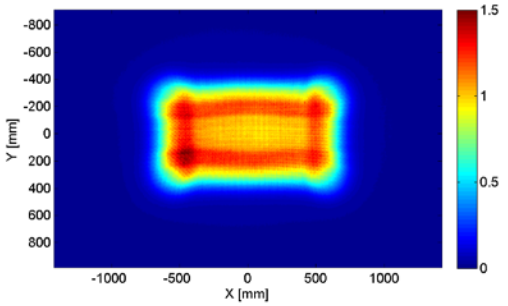
IpDip Master
x-FOI (75%) = 61.5°
Sigma = 10%



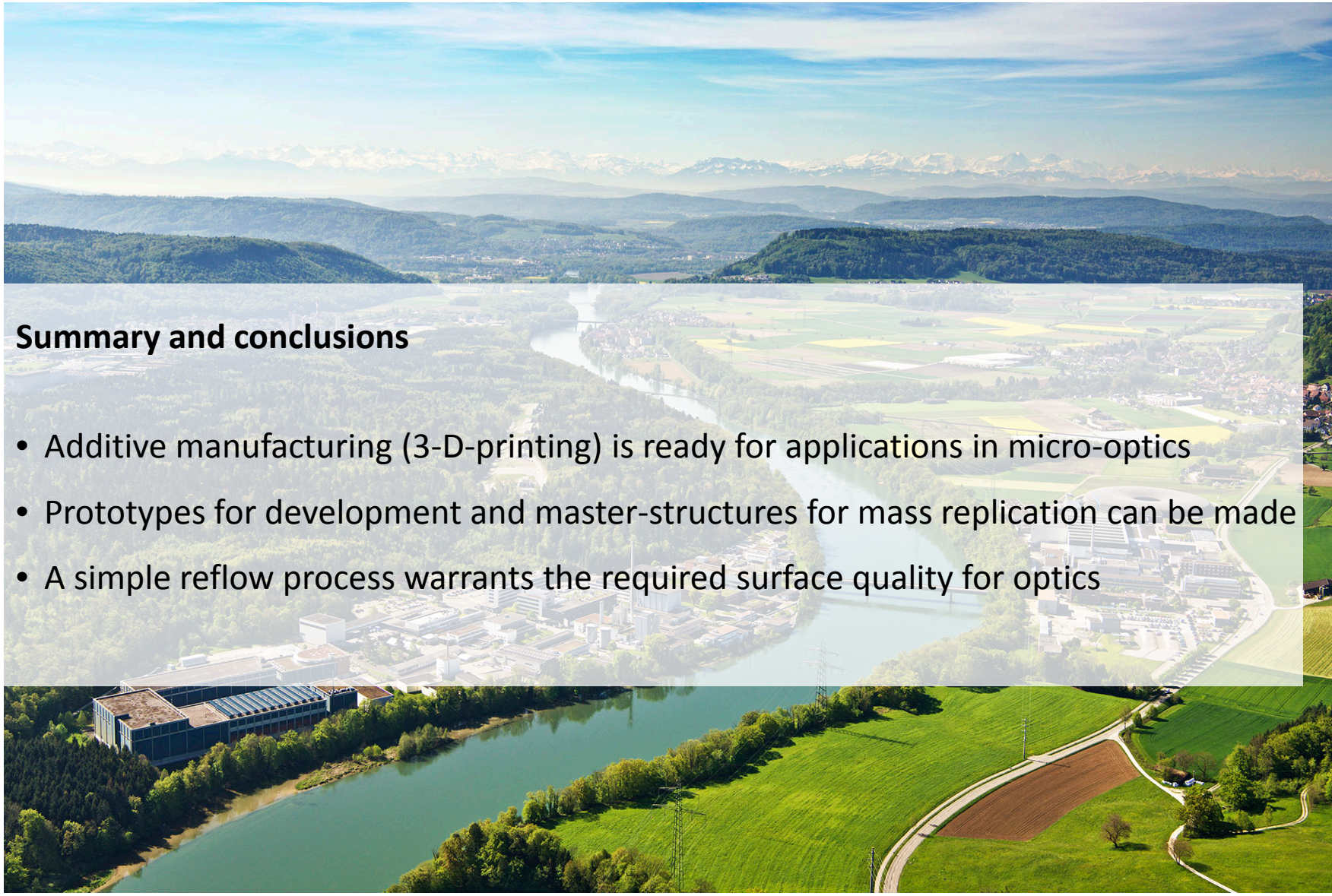
PMMA as embossed
x-FOI (75%) = 75°
Sigma = 10%



PMMA exp+reflow
x-FOI (75%) = 74.5°
Sigma = 5%



PMMA no exp reflow
x-FOI (75%) = 63.2°
Sigma = 7%



Summary and conclusions

- Additive manufacturing (3-D-printing) is ready for applications in micro-optics
- Prototypes for development and master-structures for mass replication can be made
- A simple reflow process warrants the required surface quality for optics

My thanks go to

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- M. Altana, Heptagon Oy, Zürich

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