Helmut Schift :: Polymer Nanotechnology Group :: Paul Scherrer Institut

Additives Manufacturing für optische 3D-Mikrostrukturen

swiss mnt network :: Trends in Micro Nano :: INNOCAMPUS
Biel/Bienne :: 25 Oct 2016

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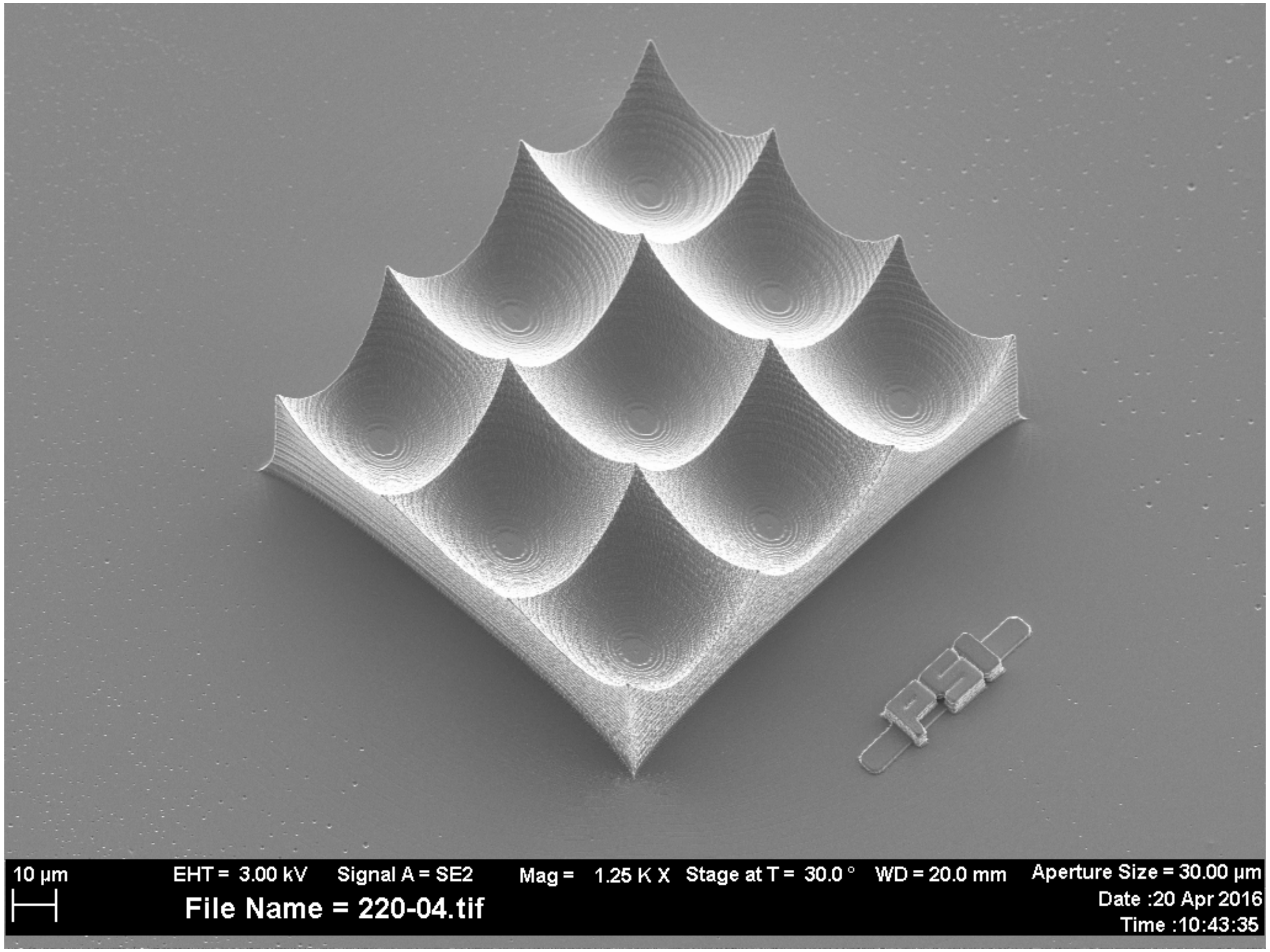
- Additives Manufacturing im (sub-)Mikrometerbereich
- Problem Oberflächenrauhigkeit und Reflow-Verfahren
- Beispiel: Mikro-Optik
- Zusammenfassung

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

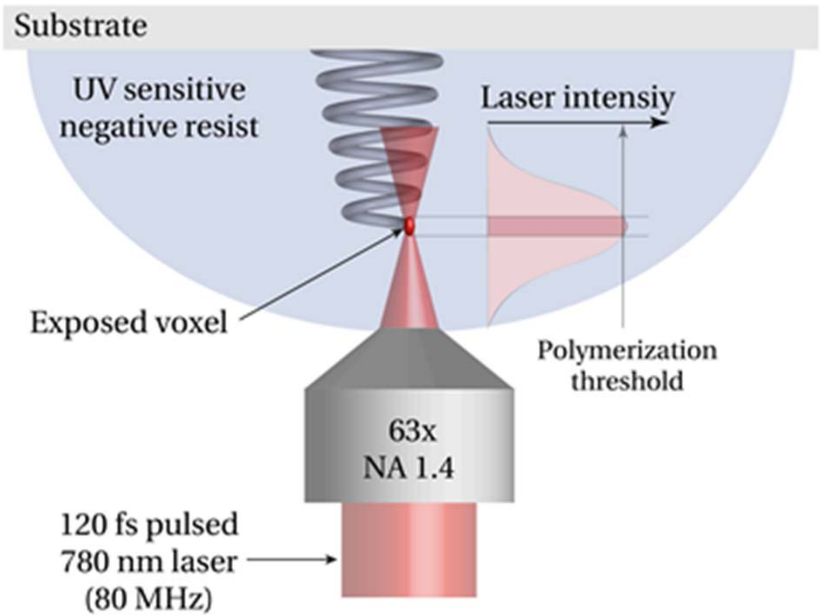
Motivation

Surfaces of microstructures are typically «rough» in different dimensions

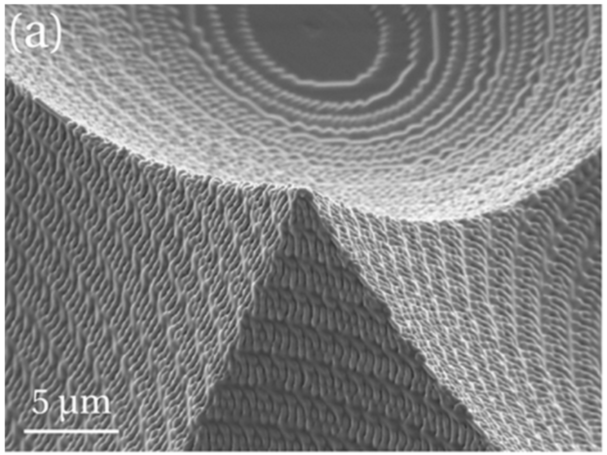


Test structure: Micro-lens array (3x3) concave 50 µm x 50 µm x 50 µm (each)

2 Photon Polymerization Technique



Surface roughness
may be a problem
in optical applications



www.nanoscribe.de

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Motivation

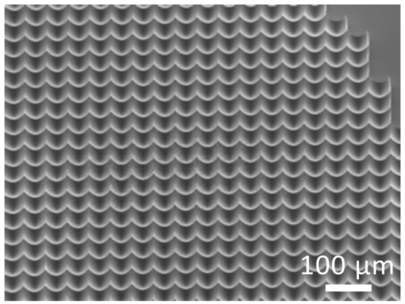
Boundary conditions and requirements

Where do we need smooth surfaces & how important is shape accuracy/curvature?

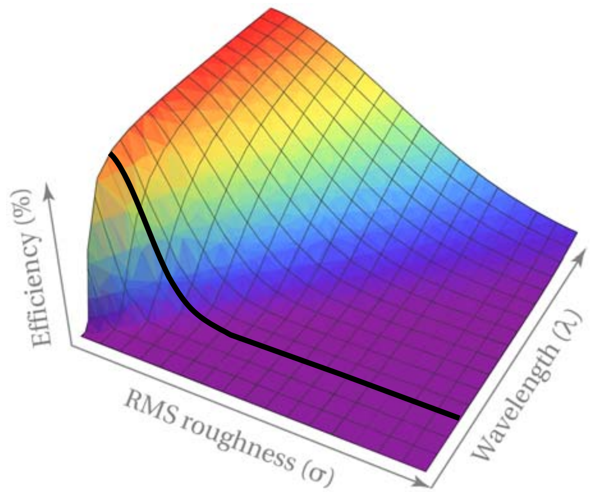
Why do we need them & how smooth is good enough?

Direct laser writing: 1-photon or 2-photon absorption?

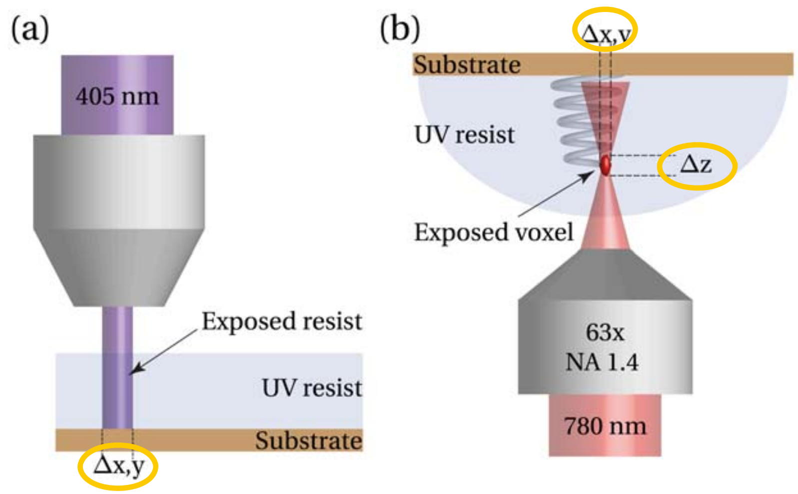
Target application:



Refractive micro optics



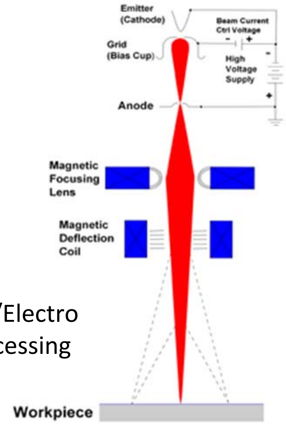
Efficiency $\frac{R_s}{R_0} = \exp\left[\frac{-(4\pi\sigma^2)}{\lambda^2}\right]$



Voxel volume $= \frac{\lambda^3}{20}$

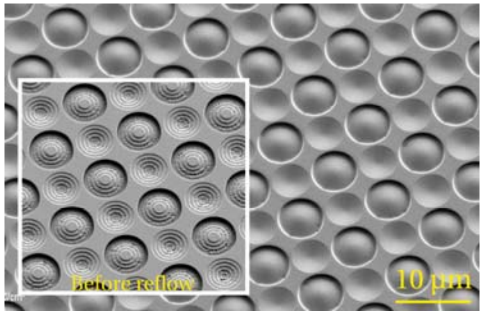
Fabrication techniques for “3D structures”

E-beam lithography



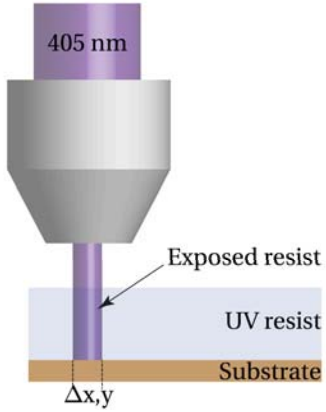
wikipedia.org/Electron_beam_processing

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

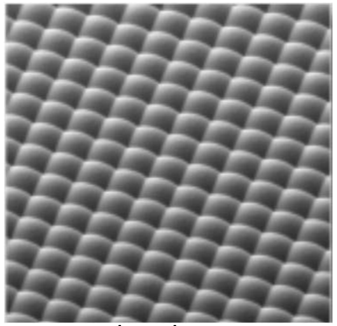


A. Schleunitz NC 2014

Direct Laser Exposure



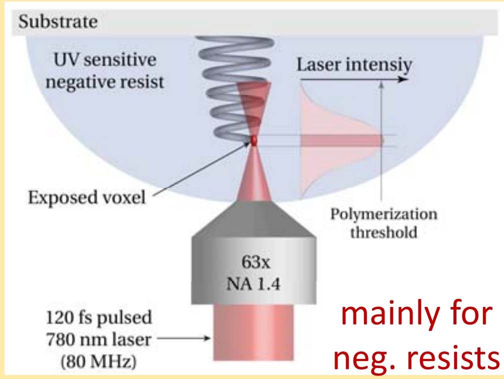
- OK resolution
- Good stitching
- Fast writing times
- Tall features not possible
- No substrate effect



MLA, 20 µm height, 100 µm pitch

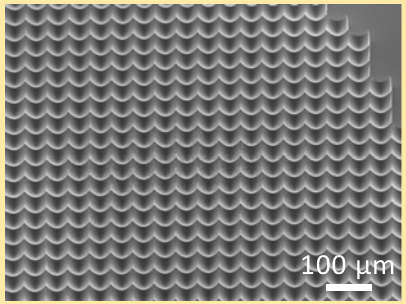
Heidelberg Instruments, DWL Series

2 photon polymerization



mainly for neg. resists

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



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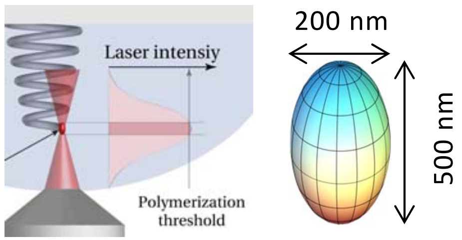
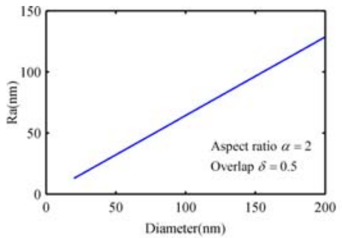
But.... Roughness concern in 2PP

Voxel size

- Polymerization threshold and laser dose

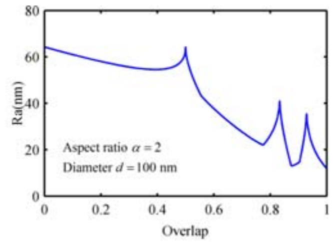


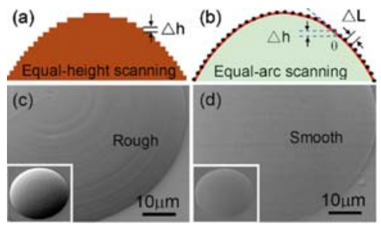


- Long writing times
- Very small head room
- Increasing voxel size???
- No shape change

Writing strategies

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



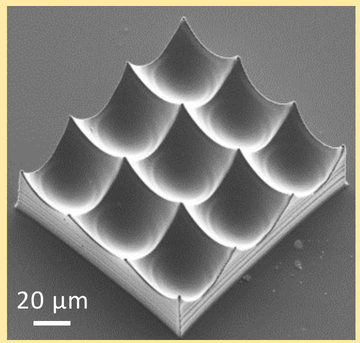


- Long writing times
- Limited process window
- Shifting from Δz to Δx
- No shape change

X. Zhou AIP Adv 2015

Post processing

- «Reflow» of resist
- Replication might be required



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

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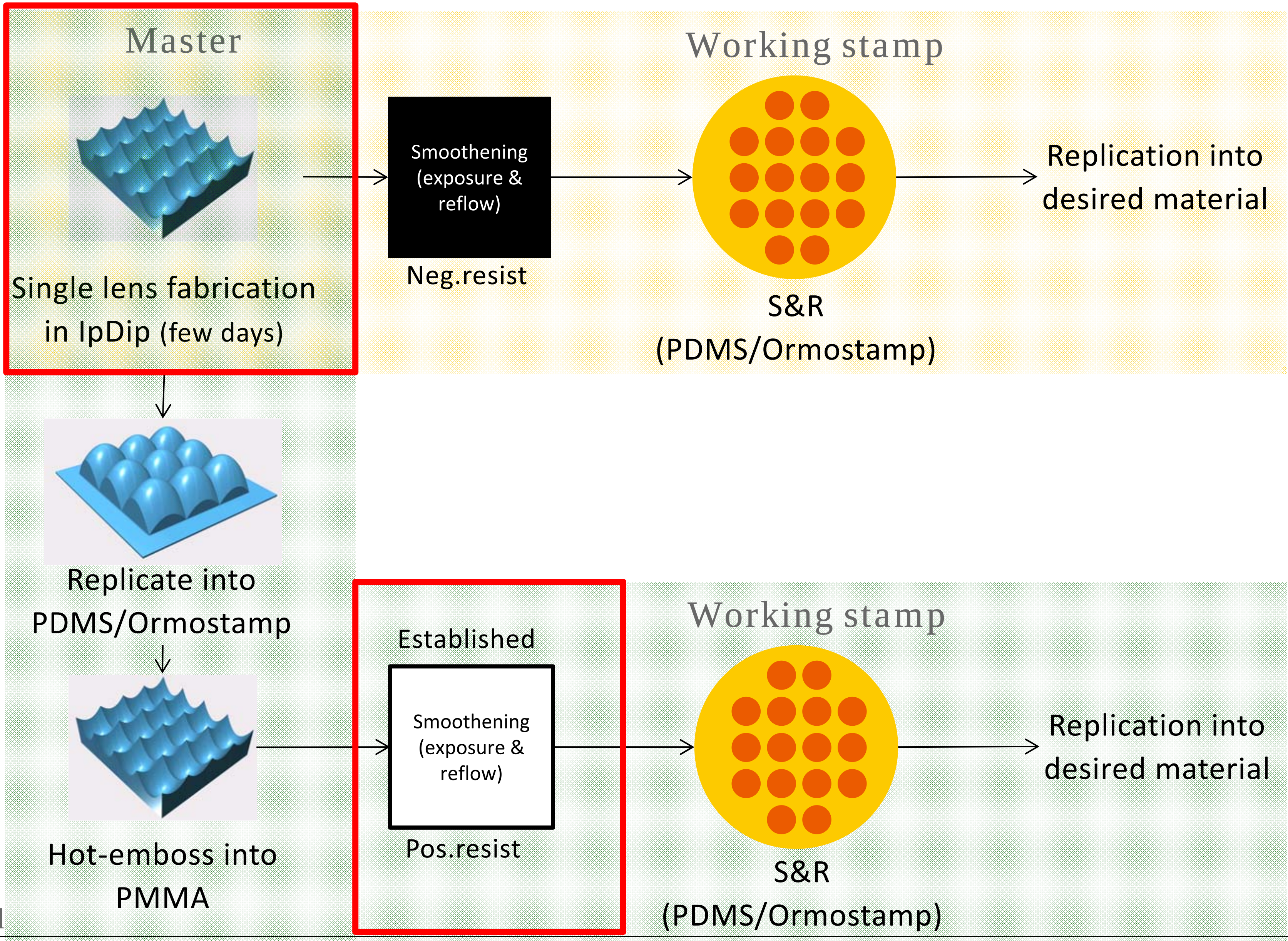
D. Wu APL 2010

Process flow with NanoScribe MLA



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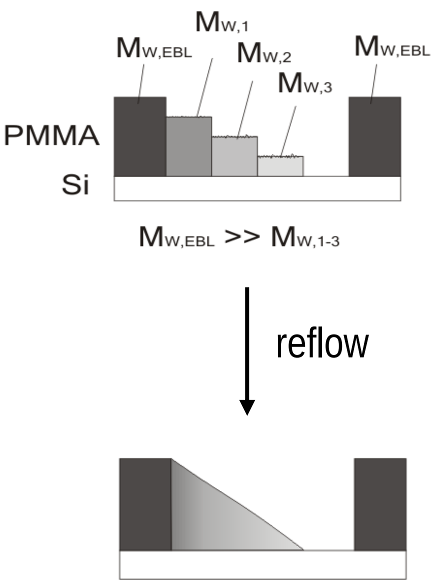
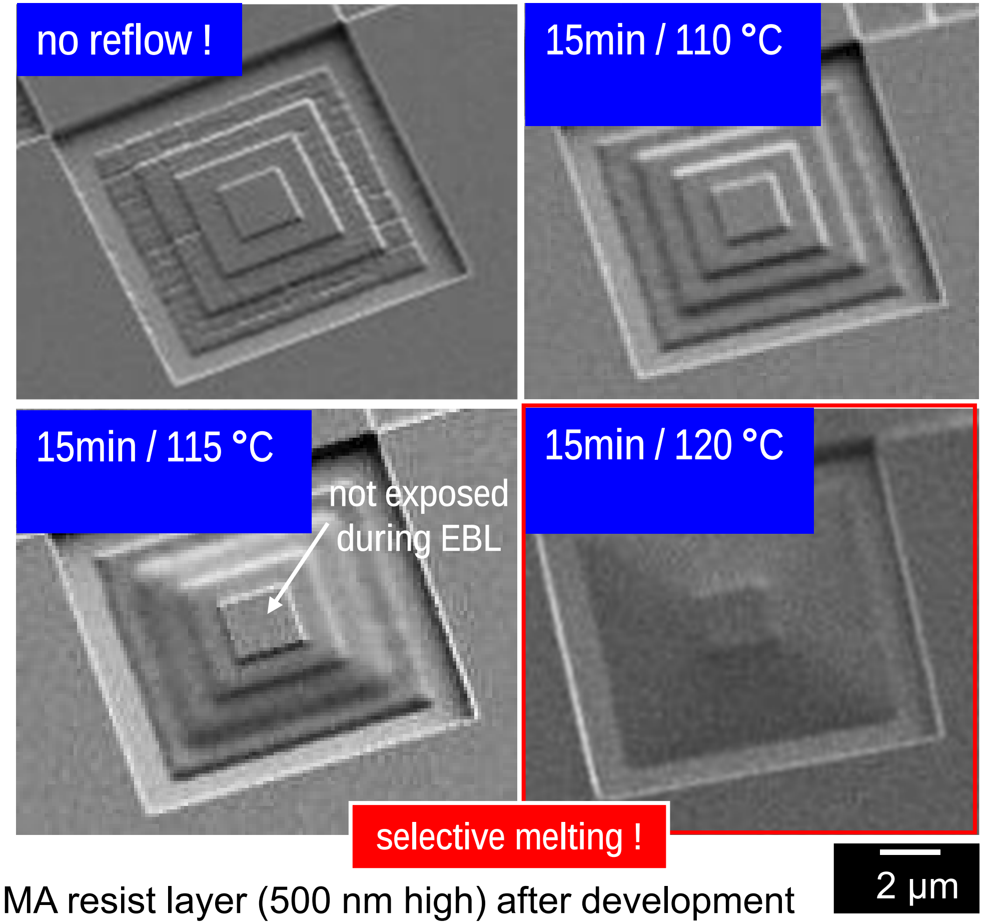
Application Example: 3-D stepped structure

Idea: Thermal post-processing of 3-D resist pattern for removal of electron beam lithography induced surface roughness

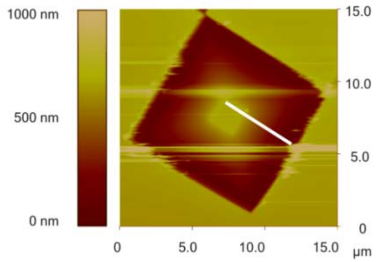
resist pattern / molecular weights

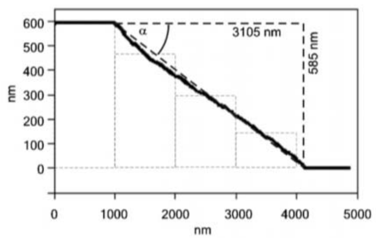




PMMA resist layer (500 nm high) after development

AFM analysis



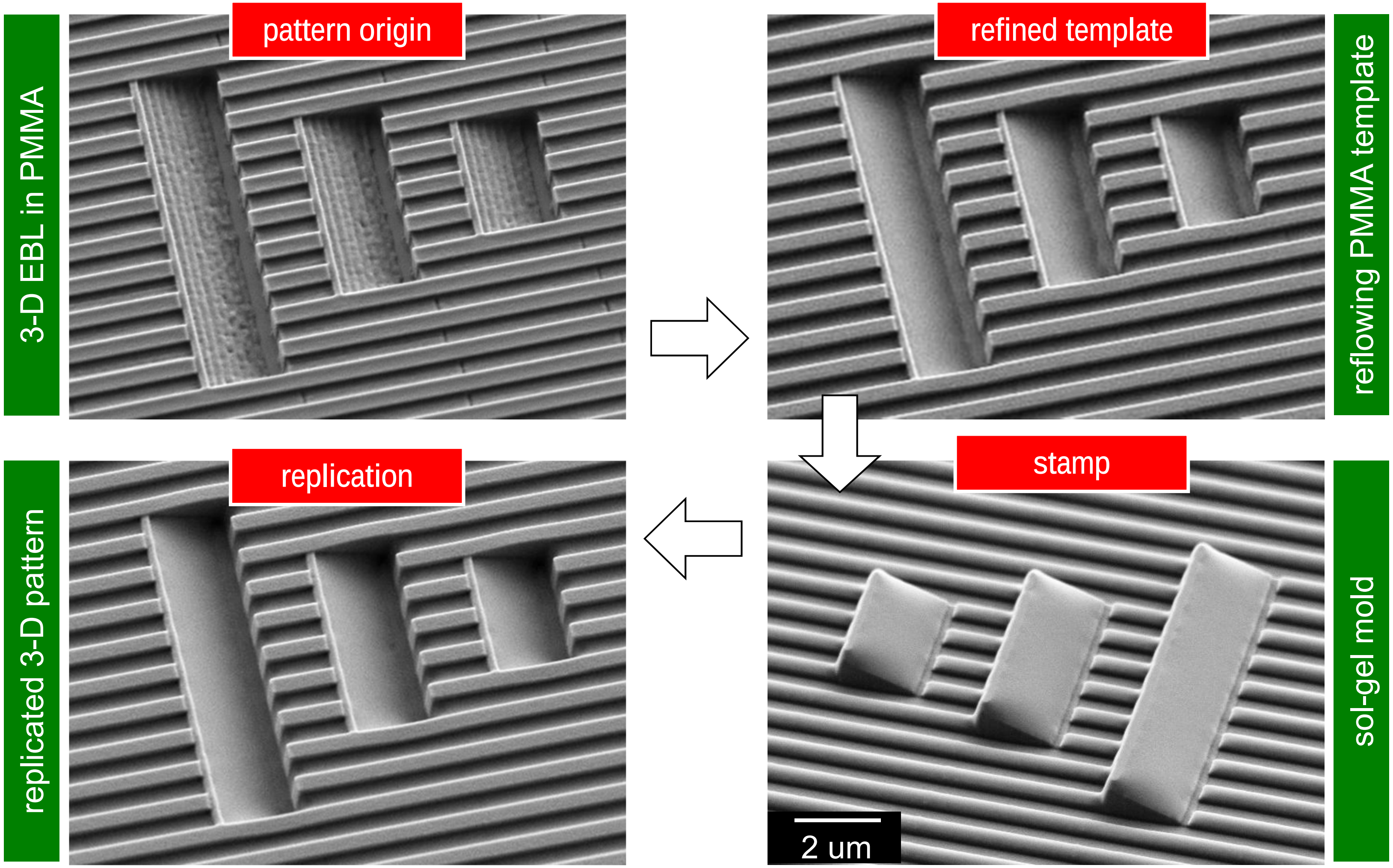


slope inclination ~ 11 °

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

Application Example: 3-D stepped structure

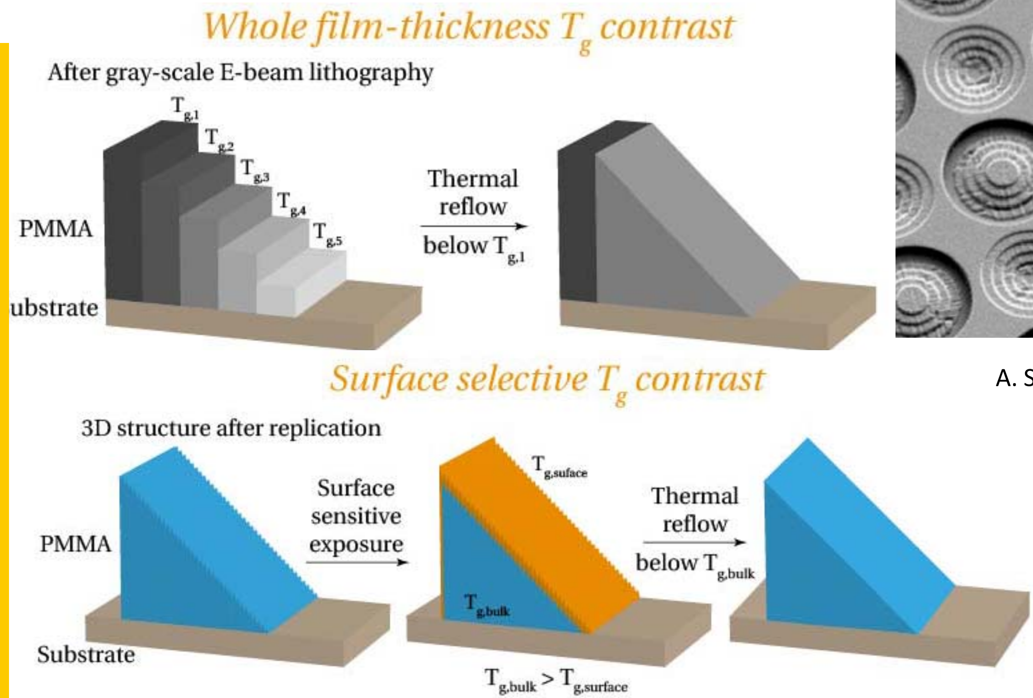
A post-processed hybrid 3-D prism/grating pattern is copied into a sol-gel material and replicated into a polymer foil

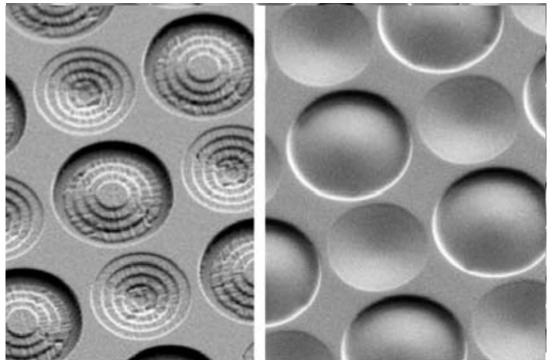


Surface sensitive damage

TASTE Process

Thermally
Activated
Selective
Topography
Equilibration





A. Schleunitz NanoConvergence 2014

High energy E-beam
- High damage
- Ambient conditions

Low energy E-beam
- Tedious/vacuum

~~Ion beam (O_2 or Ar plasma)~~
- Etching technique
- Vacuum process

285 nm UV Ozone
- Larger penetration depths
- Ambient conditions

172 nm VUV
- Reasonable penetration (100-200 nm)
- Ambient conditions

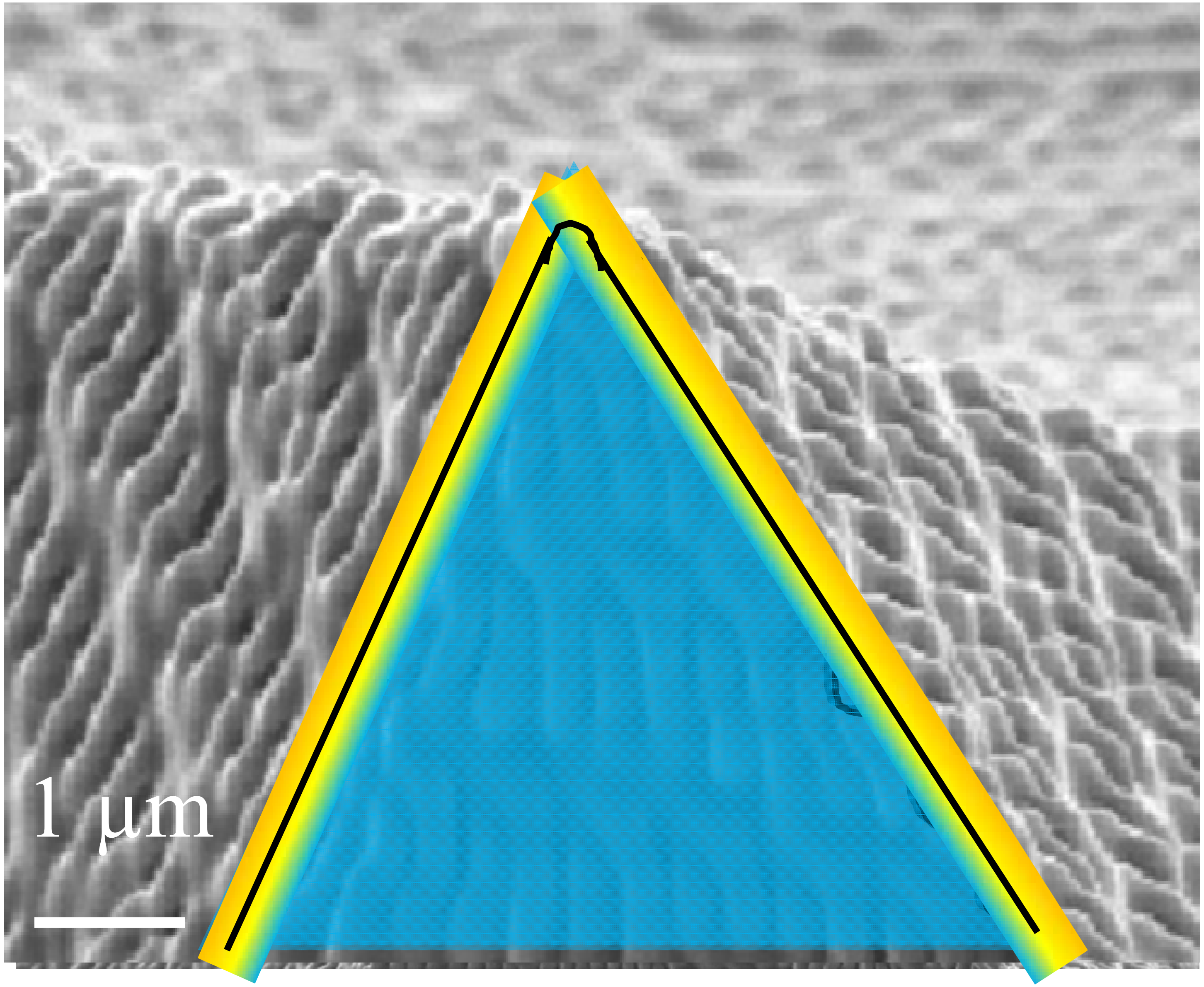
13.6 nm EUV
- Small penetration (100 nm)
- Vacuum process
- Expensive

1 nm Soft X-Rays
- Large penetration (100 µm)
- Ambient conditions

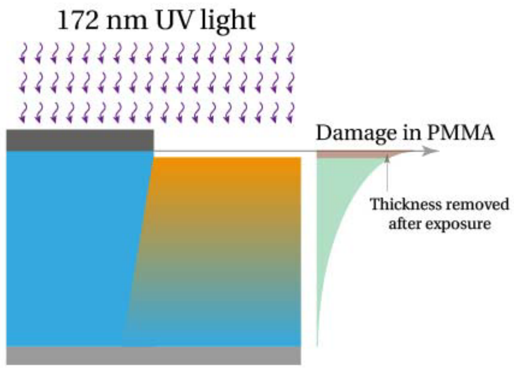
Surface sensitive damage

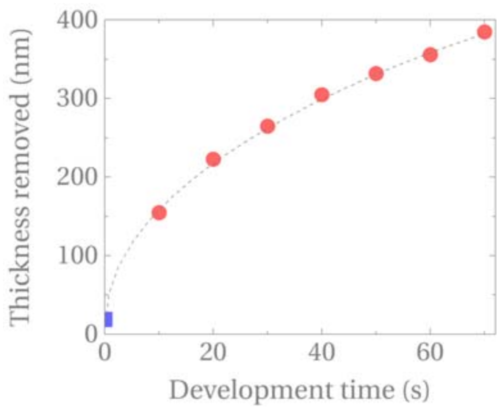
TASTE
Process

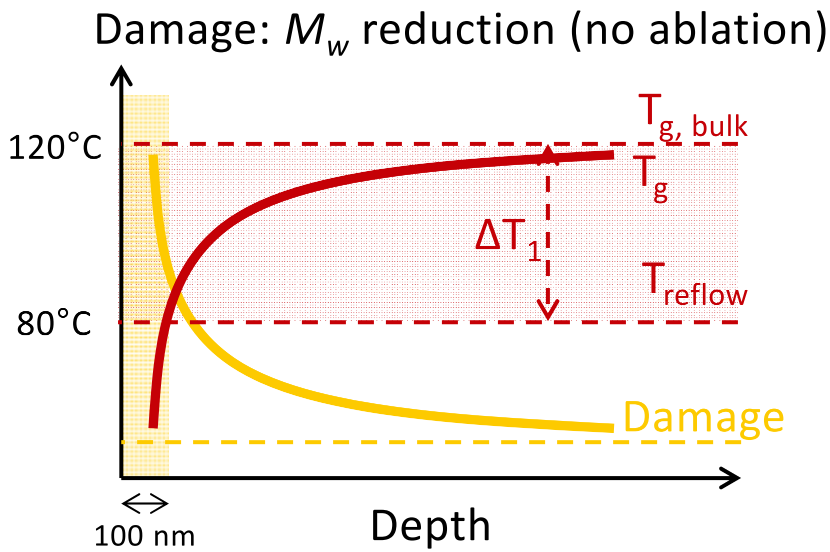
Thermally
Activated
Selective
Topography
Equilibration



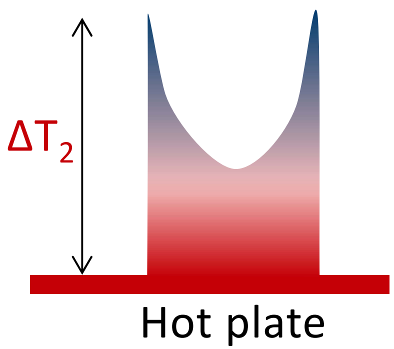
Surface sensitive damage

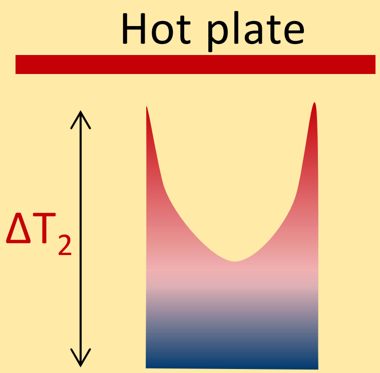






$$\Delta T_1 = T_{g,bulk} - T_{reflow(100nm)}$$
$$\Delta T_2 = T_{bottom} - T_{top}$$

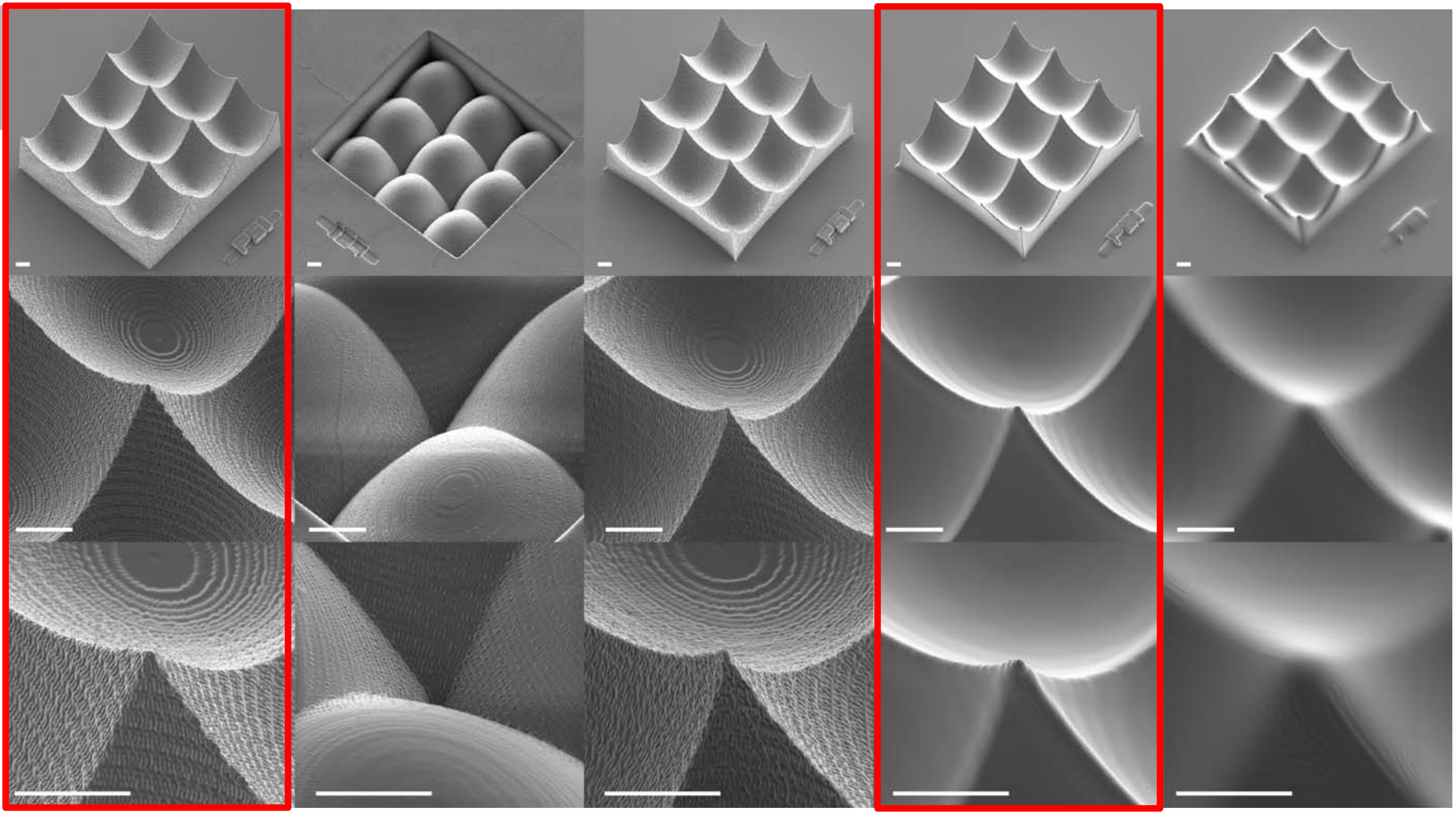




Process latitude = $\Delta T_1 - \Delta T_2$

Micro lens array

IpDip UV PDMS PMMA Reflow (exp) Reflow (no exp)



Scale = 10 µm

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