Modules of the 2025 course

Topics covered	No	Lecture/Date
VAT Photo polymerization (history) – DLP printer – light engine – part I	5	20.03.2025
DLP printer – chemical components in a photoresin – role of oxygen – CLIP method– part II	6	27.03.2025
Tomographic Volumetric Additive Manufacturing (TVAM): principles and applications	7	03.04.2025
Two photon Polymerization : nanoscale printing	8	10.04.2025
Two photon Polymerization : applications	9	17.04.2025
EASTER BREAK		22.04.2025
Prof. Paul Dalton, University of Oregon: Met Electro Writing (nanoscale)	10	1.05.2025
Gari Arutinov, Holst Center for AM: Mass transfer of microcomponents	11	08.05.2025
Julian Schneider: Scrona	12	15.05.2025
Patrizia Richner: Sonova (hearing aids). // **Design Competition**	13	22.05.2025

QUIZZ #2

Although the wavelength is 780nm,
It is possible to make structures
With size 65 nm !!

By adjusting the dose i.e

$$Intensity \; * exposure \; times$$

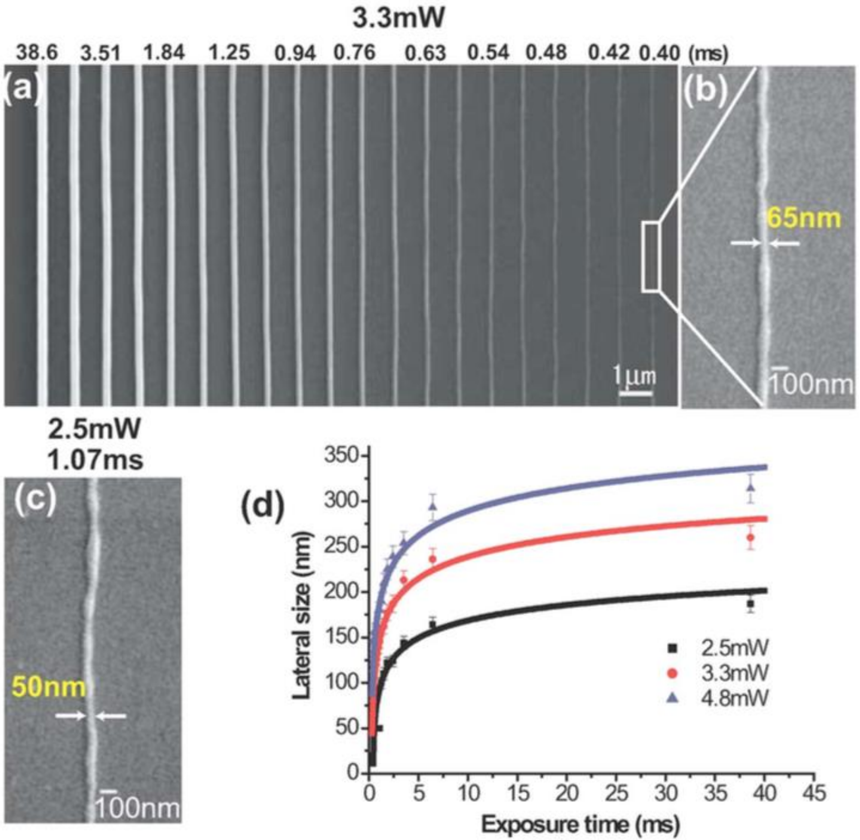
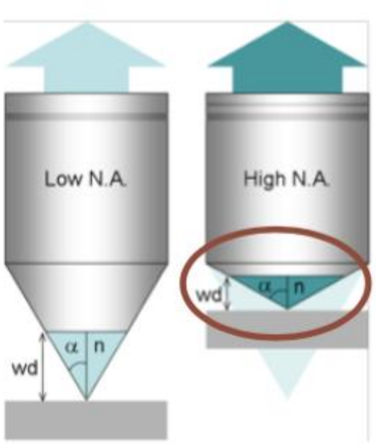
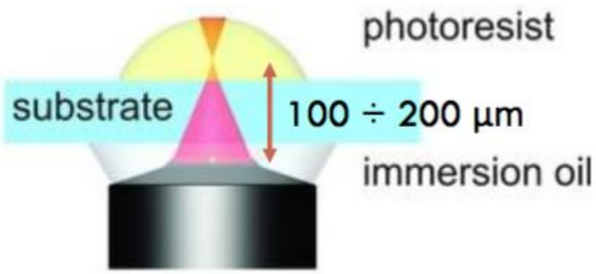


FIG. 2. (Color online) (a) SEM images of photocured polymer lines obtained using a laser power of 3.3 mW, after various exposure times. (b) Enlarged image of a line fabricated with a laser power of 3.3 mW and an exposure time of 0.4 ms. (c) A polymer line with a width of 50 nm. (d) LSR vs exposure time under different laser powers (lines are calculated results).

Height Limitation of 3D structures





E.G.: Zeiss Objective Plan-Apochromat 63x/1.40 Oil DIC

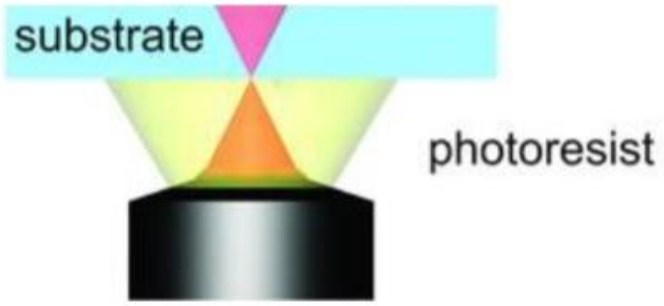
- M=63x
- NA=1.4
- WD=190 µm

Max height ~10 µm

DW: Working distance of the microscope objective i.e
The distance between the objective and the focal distance

Dip-in mode

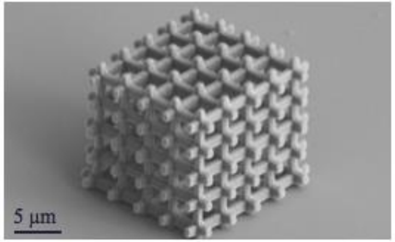
- DIP-IN

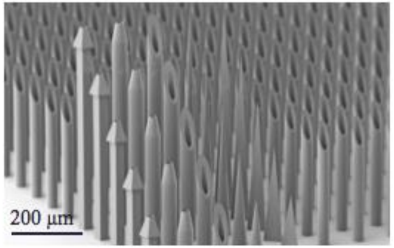


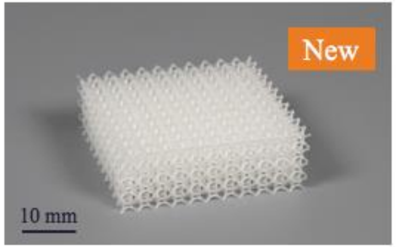
Only photoresists with matched n can be used

T. Bückmann et al., Adv. Mater., **24** 2710-2714(2012)

Dip-in mode



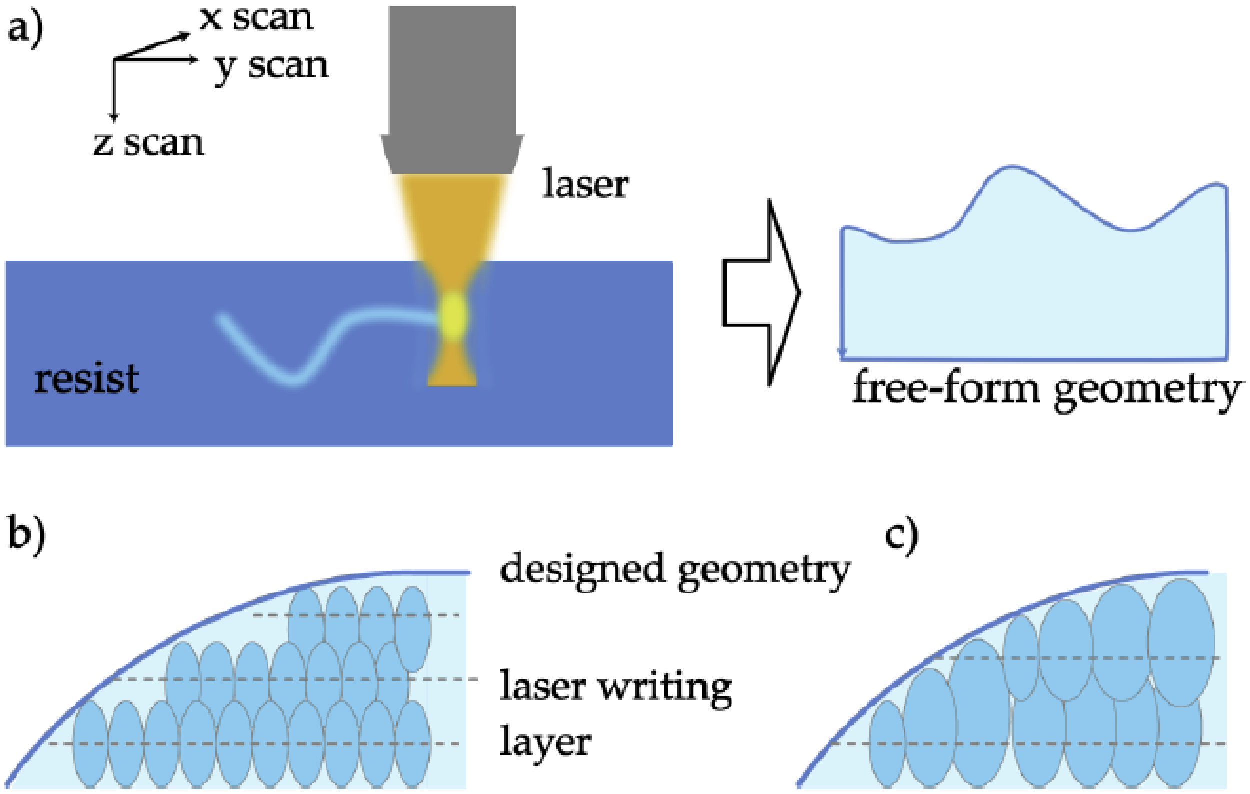




	Small feature	**Medium feature**	**Large features**	**Extra large feature**
Magnification NA	**63x** **1.4**	**25x** **0.8**	**10x** **0.3**	**5x** **0.16**
Calibrated print field diameter	**270 µm**	**700 µm**	**1,750 µm**	**3,200 µm**
Working distance	**360 µm**	**380 µm**	**2,600 µm**	**18,500 µm**
Scan speed (max.)	**100 mm/s**	**250 mm/s**	**625 mm/s**	**1,250 mm/s**
Slicing range (typical)	**0.1 – 0.8 µm**	**0.5 – 3 µm**	**2 – 10 µm**	**5 – 100 µm**

Two-photon polymerization (2PP)

Two-photon grayscale lithography (2GL)



2GL on Aspherical Singlet and Doublet

Research Article Vol. 31, No. 3 / 30 Jan 2023 / *Optics Express* 4179

Optics EXPRESS

Complex aspherical singlet and doublet microoptics by grayscale 3D printing

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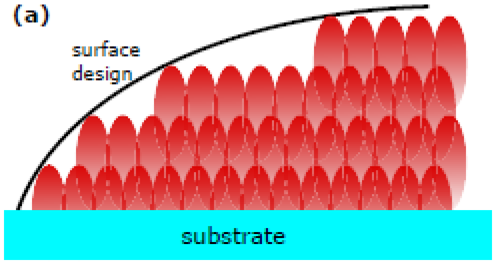
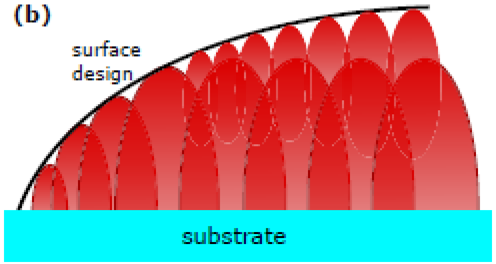
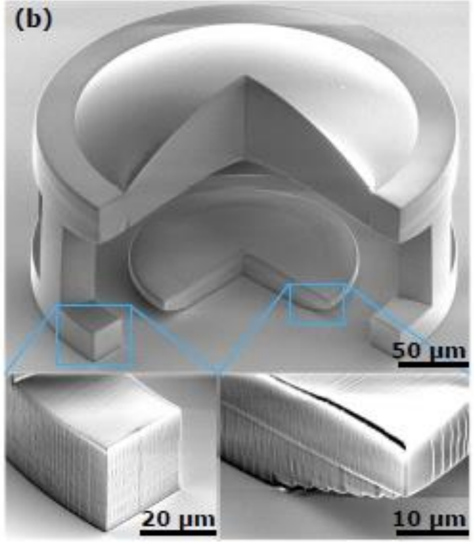
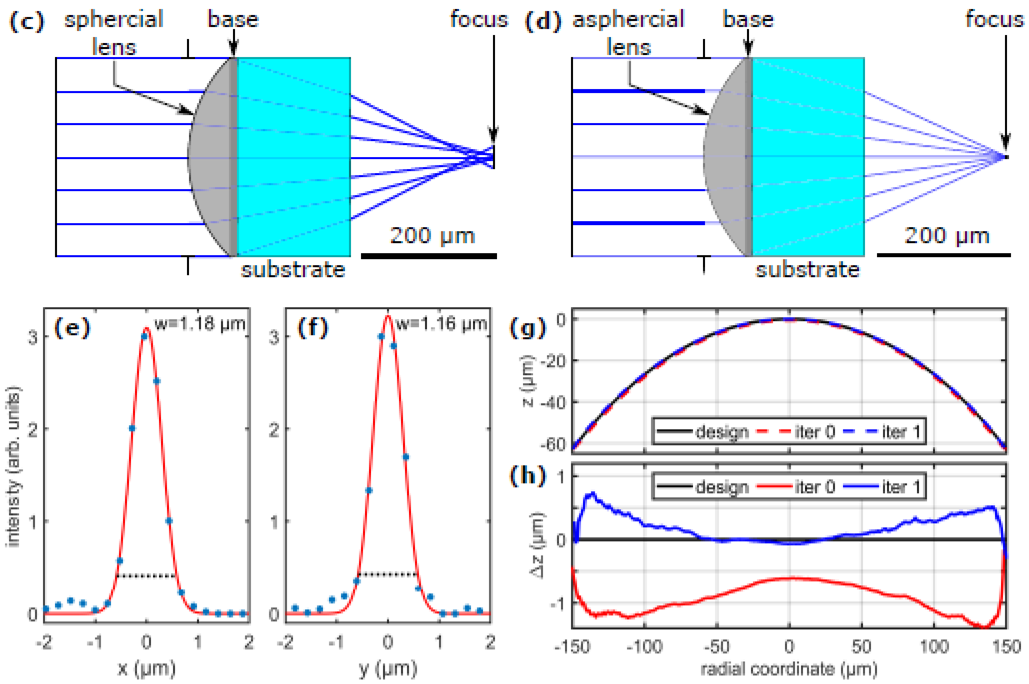
*l.siegle@pi4.uni-stuttgart.de



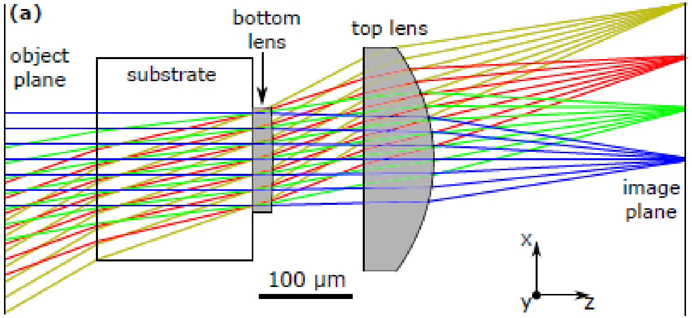


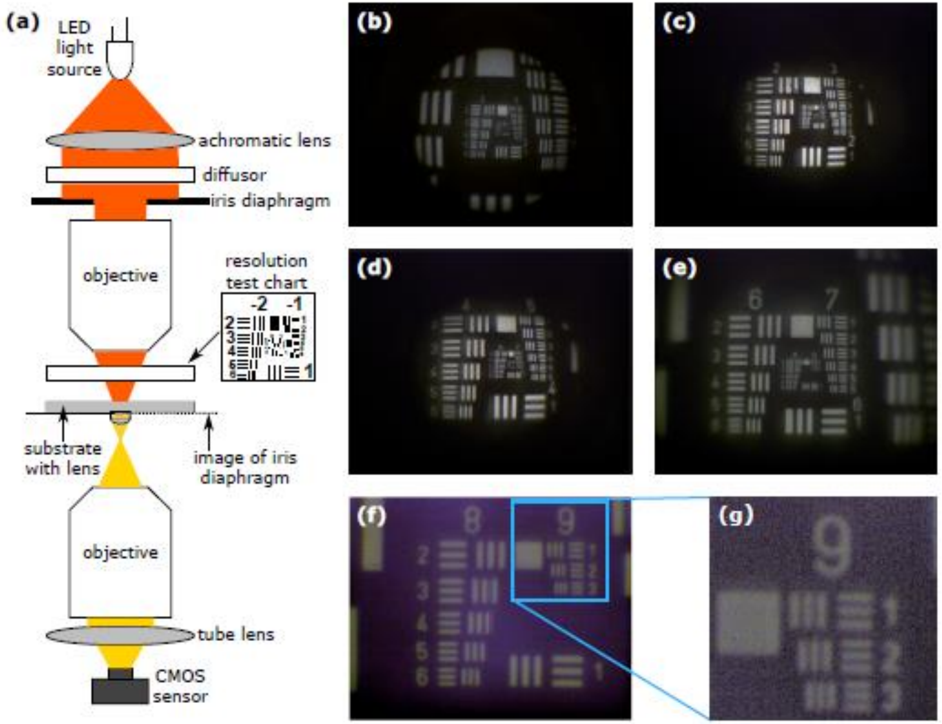


2GL on Aspherical Singlet and Doublet



2GL on Aspherical Singlet and Doublet





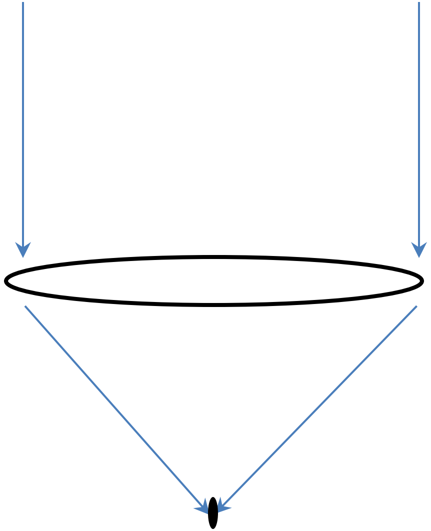
field of view of 60°
deviations 20 nm for the bottom lens
deviations 100 nm for the larger top lens
resolution 645 lp/mm

https://doi.org/10.1364/OE.480472

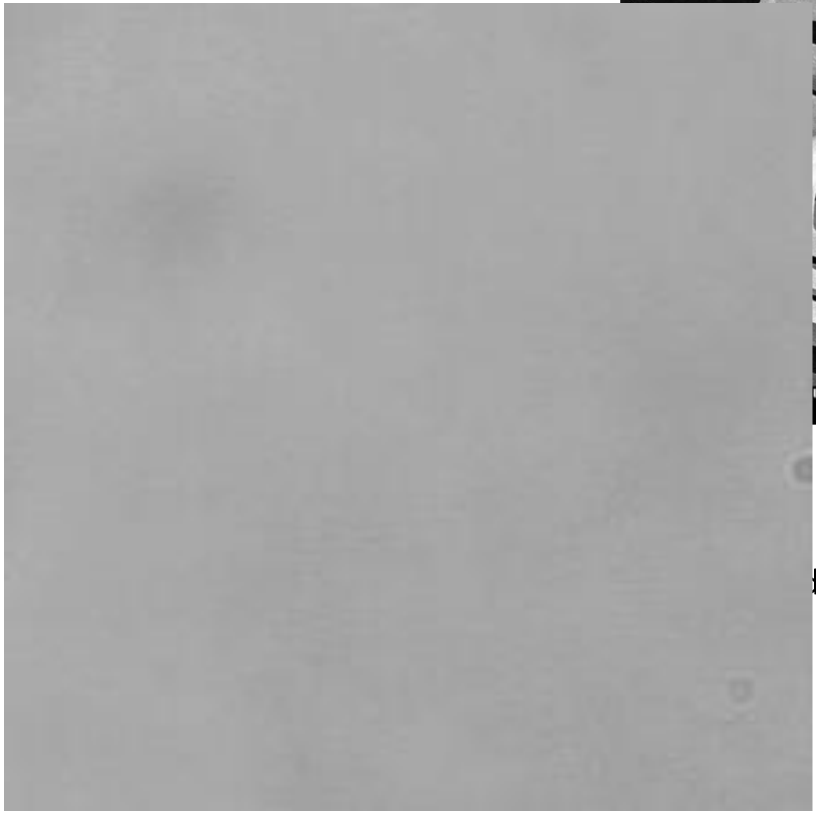
How to increase printing speed ?

Holographic multi-focus 3D two-photon polymerization with real-time calculated holograms – Optics Express 2014

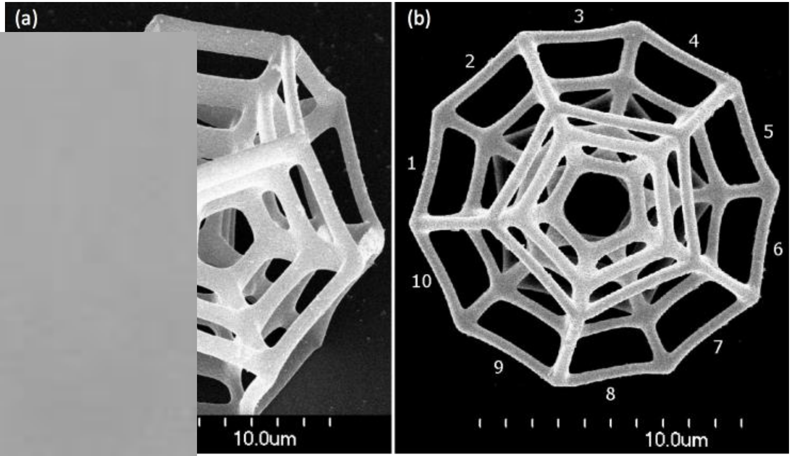
EPFL



Single focus



This can be generated by a DLP for example



into

Fabricated by 550 projections giving each 5 Foci.

Example: bio-printing

5 ms exposure, 3 mW/foci → 200 Hz
750 foci → 2.2 W

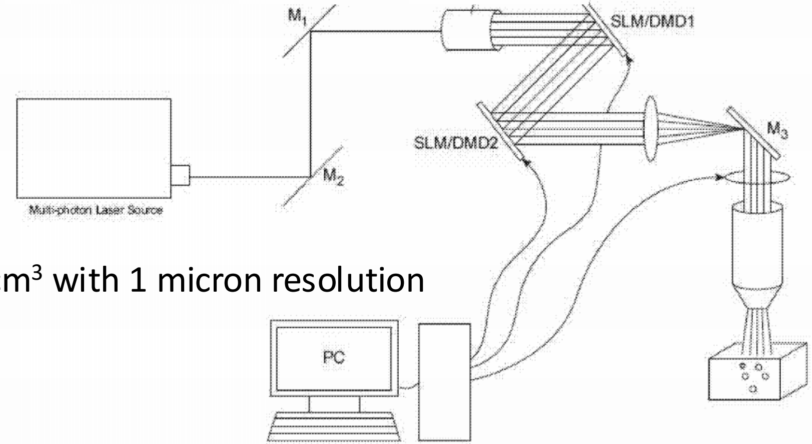
150,000
Voxels/second

(19) **United States**
(12) **Patent Application Publication**
MATHEU

(54) **METHODS AND SYSTEMS FOR PRINTING BIOLOGICAL MATERIAL**

(71) Applicant: **Prellis Biologics, Inc.**, San Francisco, CA (US)

(52)



Time to print 1 cm^3 with 1 micron resolution

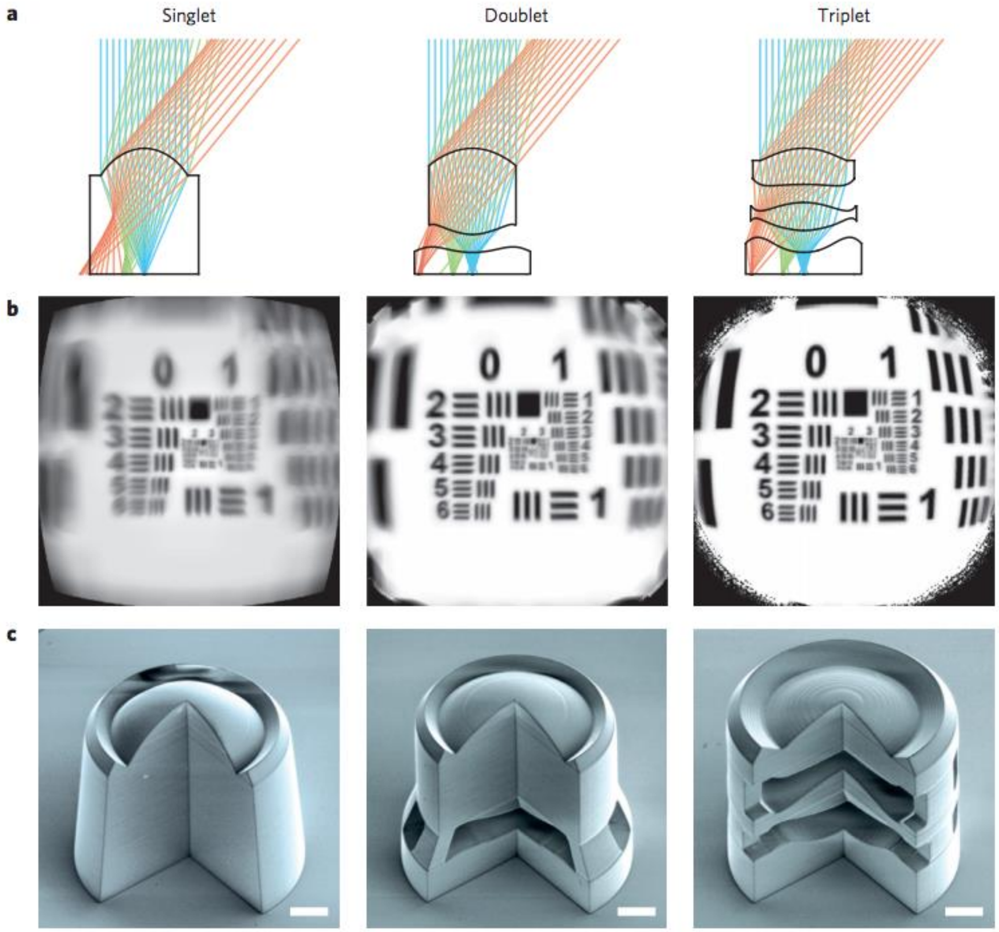
$$fab\ time = f \cdot n_{voxels}/\#voxels/sec$$

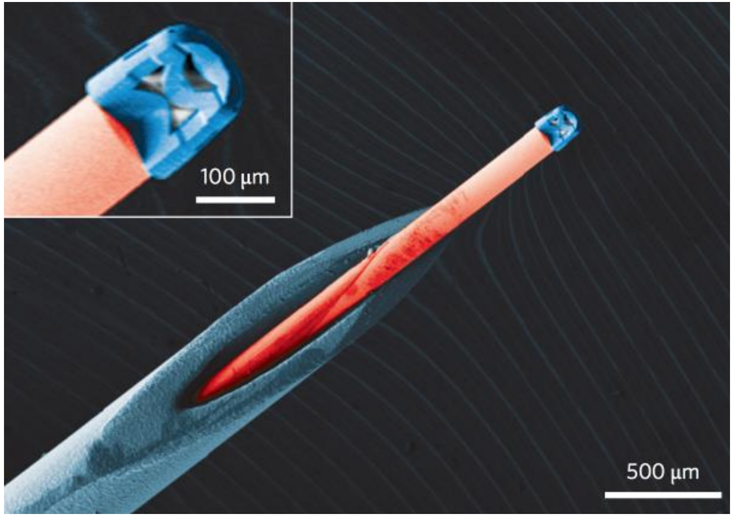
Fill factor	1%	15%
	18.5 h	11.5 days

Two-photon direct laser writing of ultracompact multi-lens objectives

nature photonics

EPFL

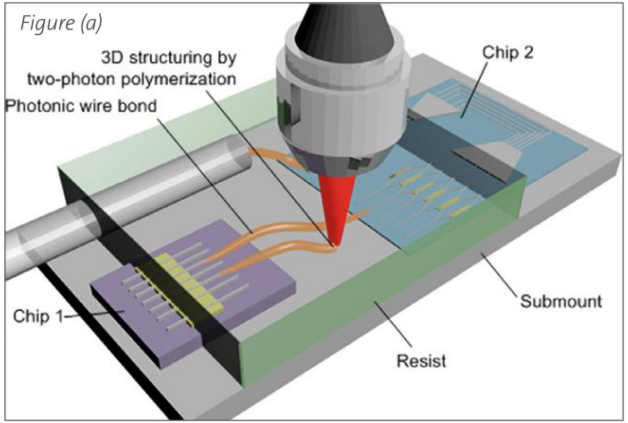


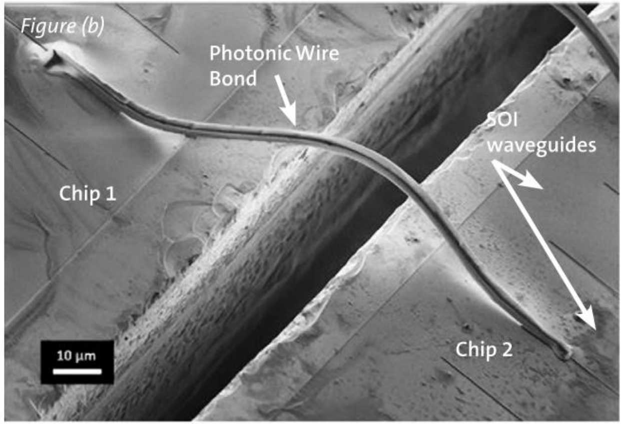


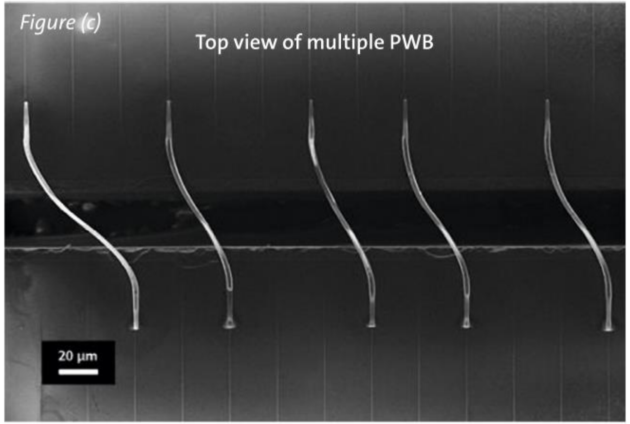
Transparent polymer material

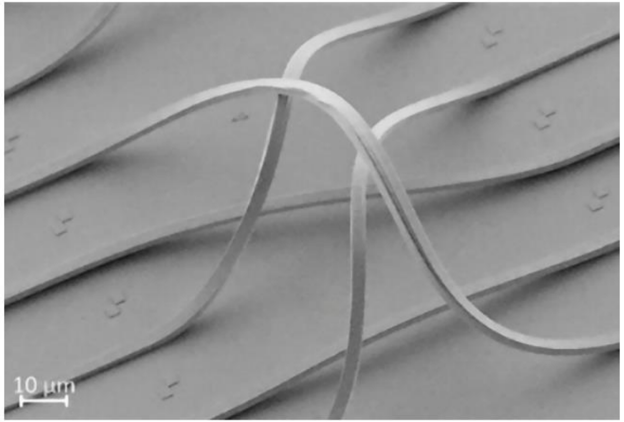
Photonic Wire bonding

Vol. 20, No. 16 / OPTICS EXPRESS 2012

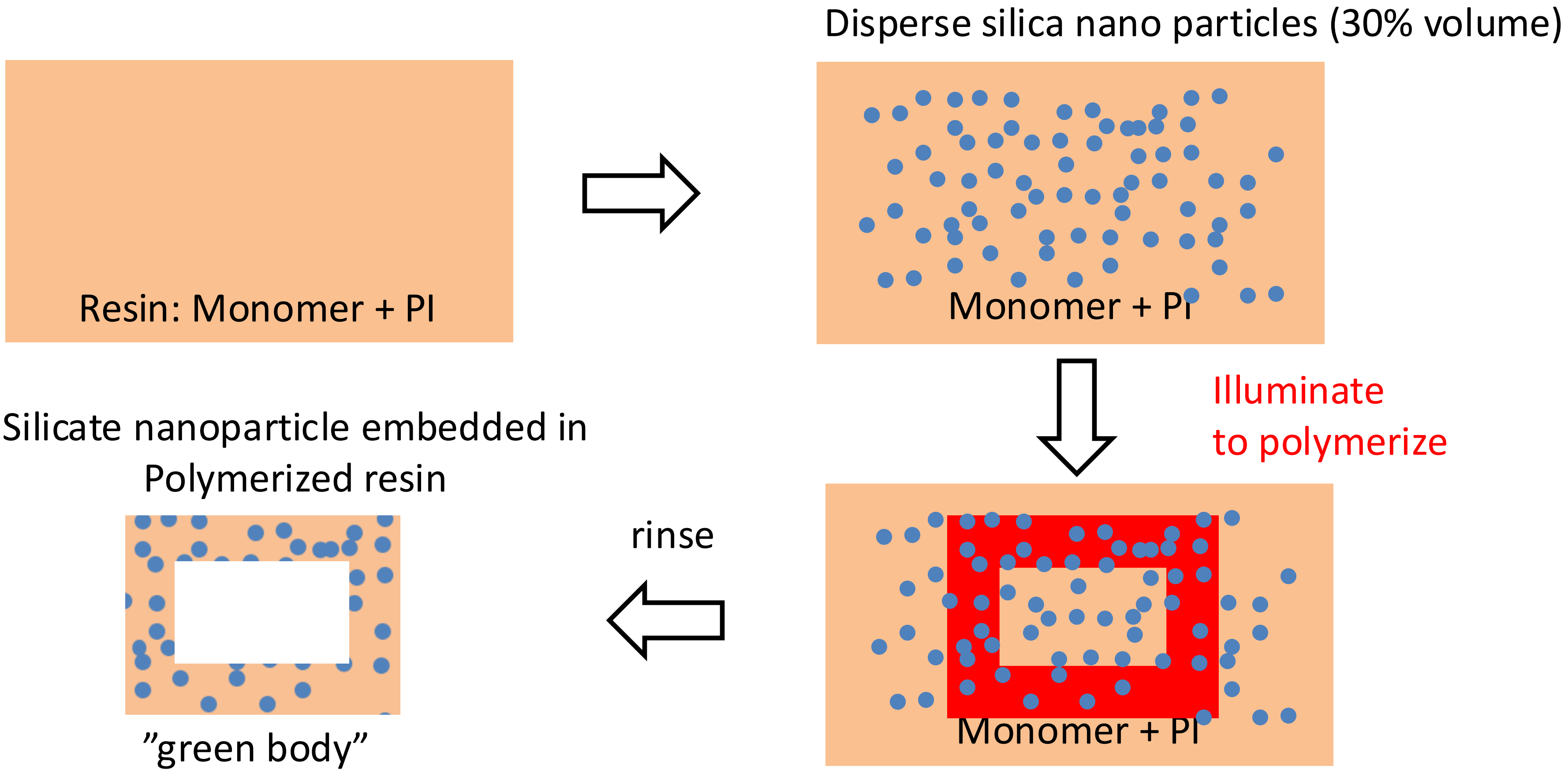




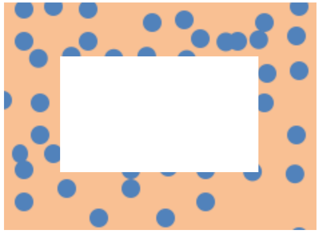


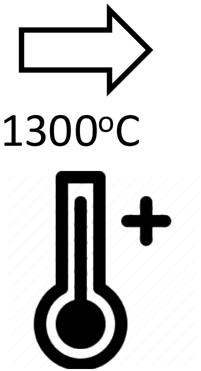


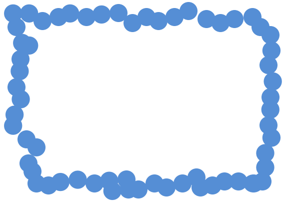
2 Photon Polymerization : glass



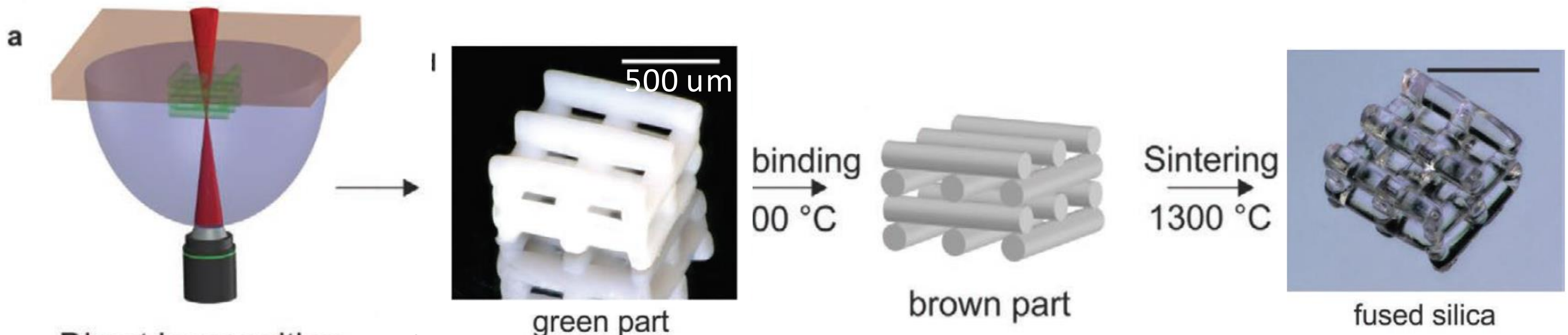
2 Photon Polymerization : glass





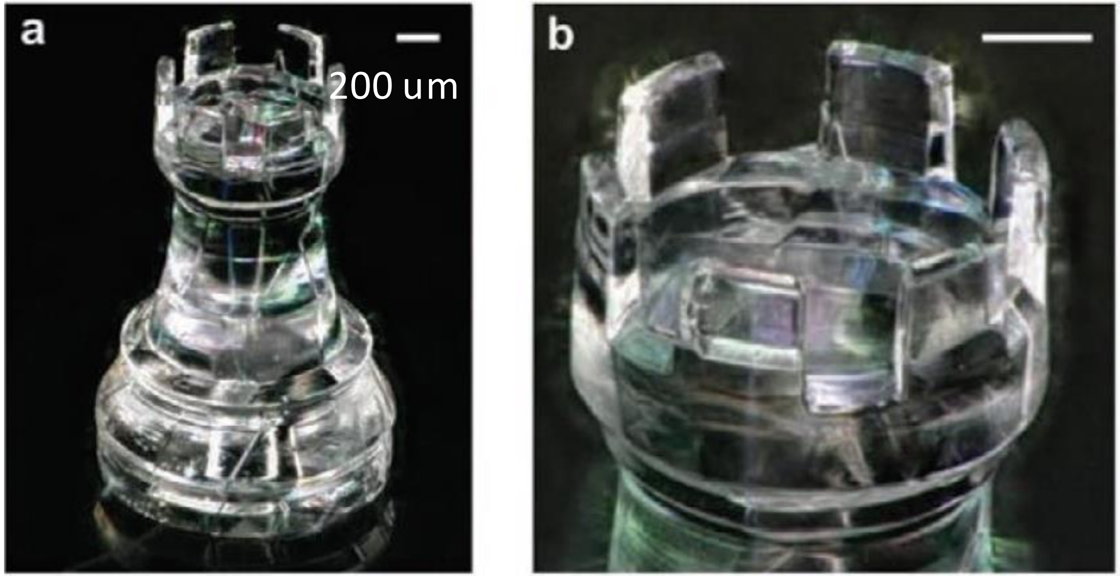


The silica particles sinter and
the polymer are vaporized by the heat
Leaving only the merged silicate particles



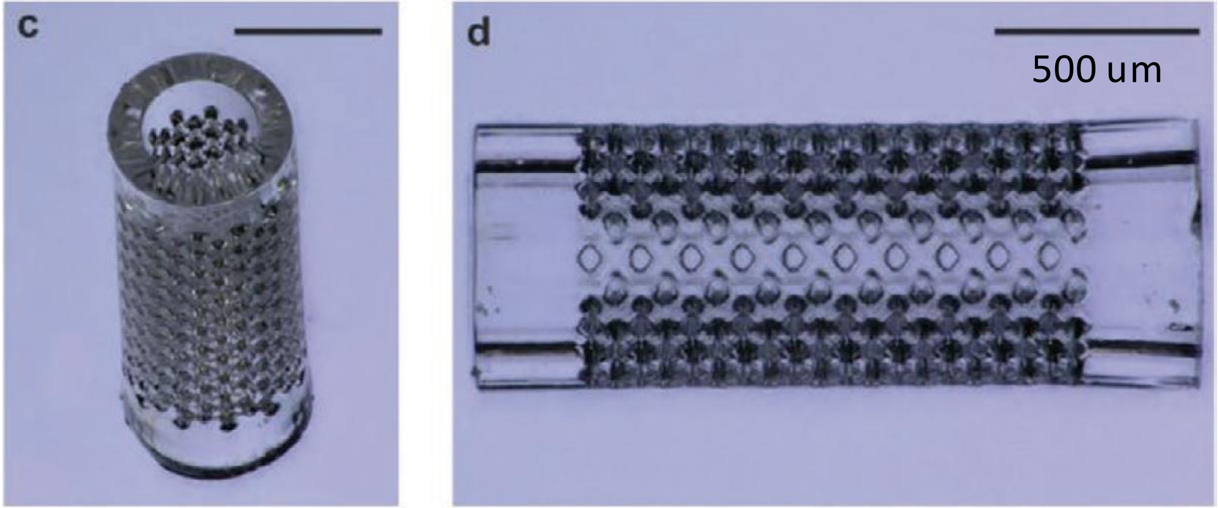
Direct laser writing=2 Photon Polymerization

Micro glass prints



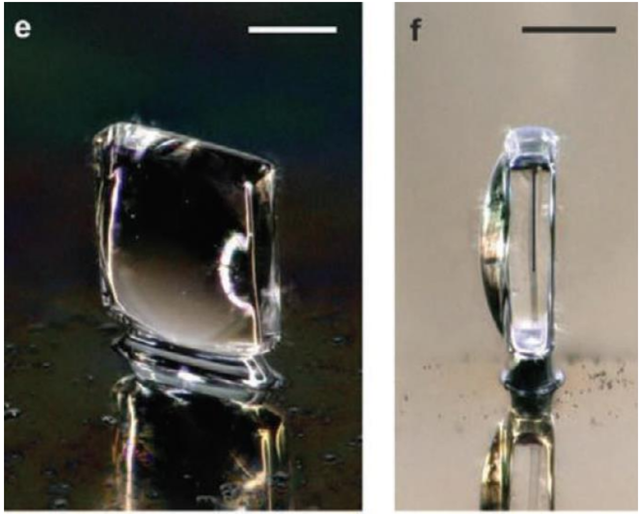
Slicing 5 μm, hatching 1 μm, scan speed 100 mms^{-1}

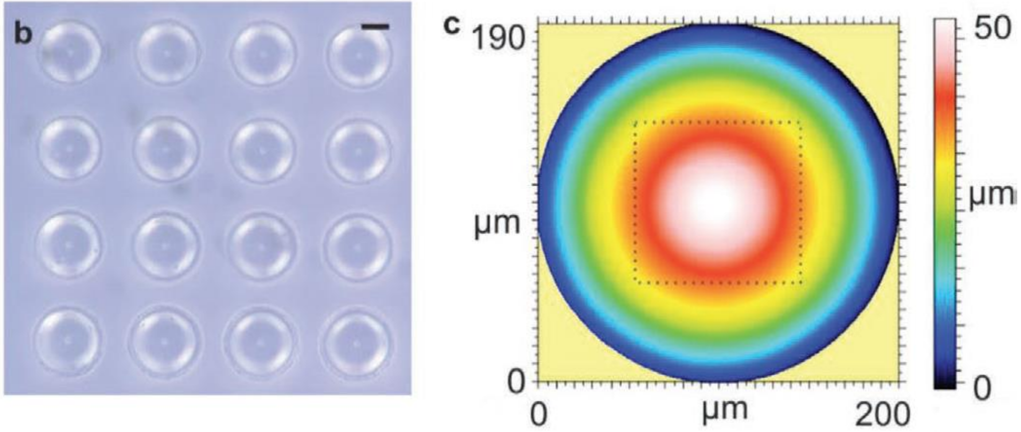
Micro glass prints



Micro filter element with 55 um holes

Slicing 5 μm, hatching 1 μm, scan speed 100 mms^{-1}



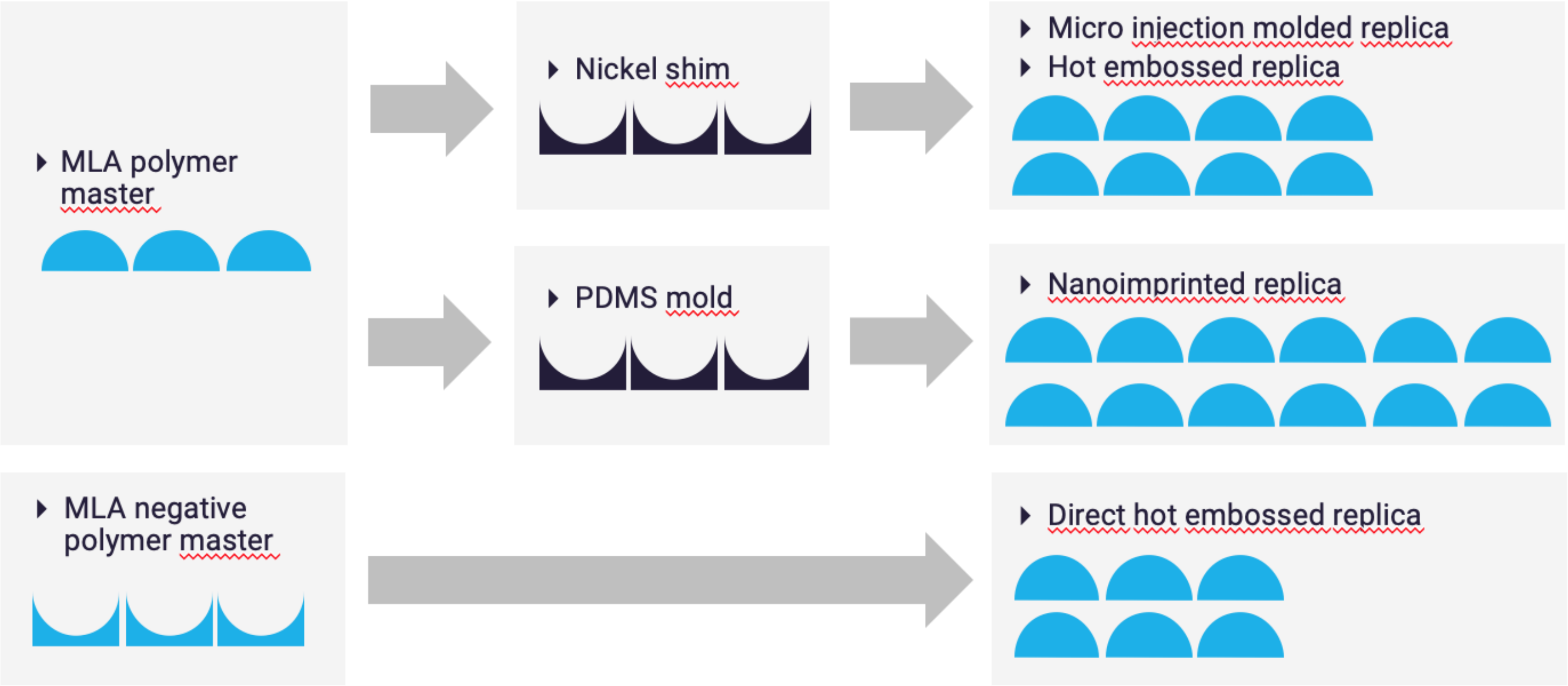


Glass micro lenses

Surface roughness Ra ≈ 6.1 nm

High precision parts for replication

Replication processes
From polymer master to small series production



2-photon
Printer
By Nanoscribe

At Cmi
BM building