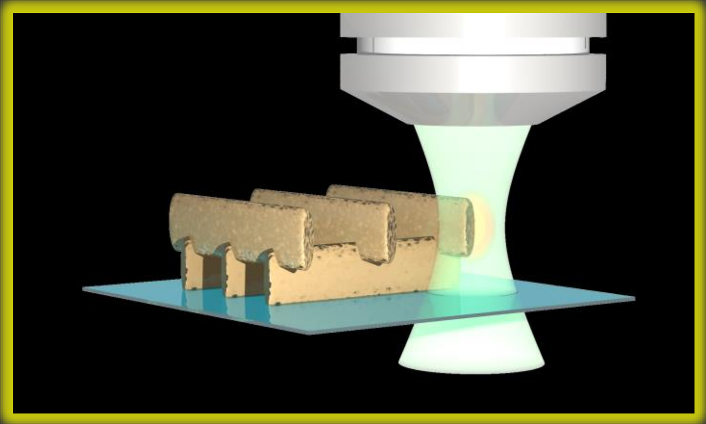
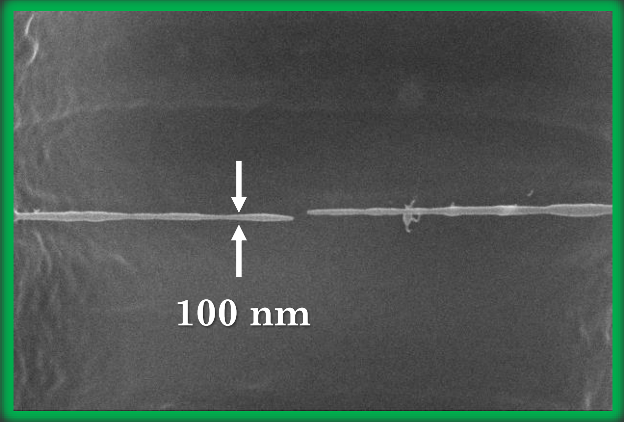
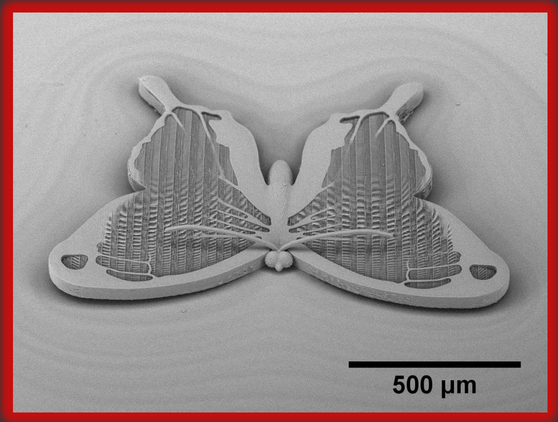
Heavy-duty and high-performance 3D micro-optics made by laser additive manufacturing







Mangirdas Malinauskas

mangirdas.malinauskas@ff.vu.lt

Laser Research Center (LRC) at Physics Faculty of Vilnius University (VU)

Saulėtekio Ave. 10, LT-10223, Vilnius, Lithuania, €U

International Online Conference on Holography Meets Advanced Manufacturing
20 - 22 February 2023

Laser Nanophotonics Group

Laser Research Center, Physics Faculty, Vilnius University

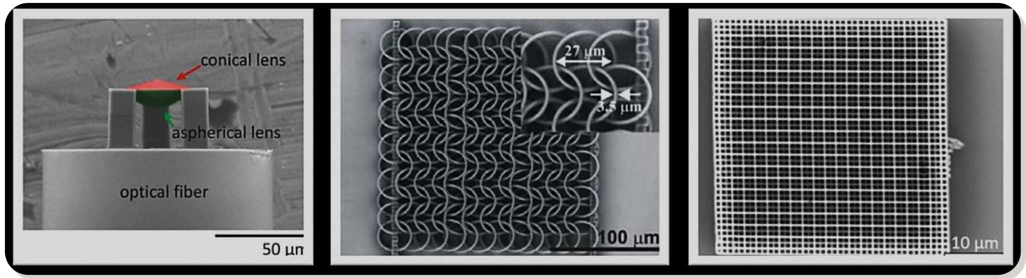
1. Investigation of the **light-mater** interaction at **DLW fabrication** conditions;

2. The development of **multifunctional** and **integrated microoptical** components for manipulation of the propagation of light;

3. Fabrication of **3D microporous scaffolds** for **biomedical applications** out of biocompatible and biodegradable materials;

4. Development and investigation of **photonic crystals** for manipulation of the **spectral and spatial** characteristics of light;

5. **Optical 3D printing** of renewable resources based **bioresins**.



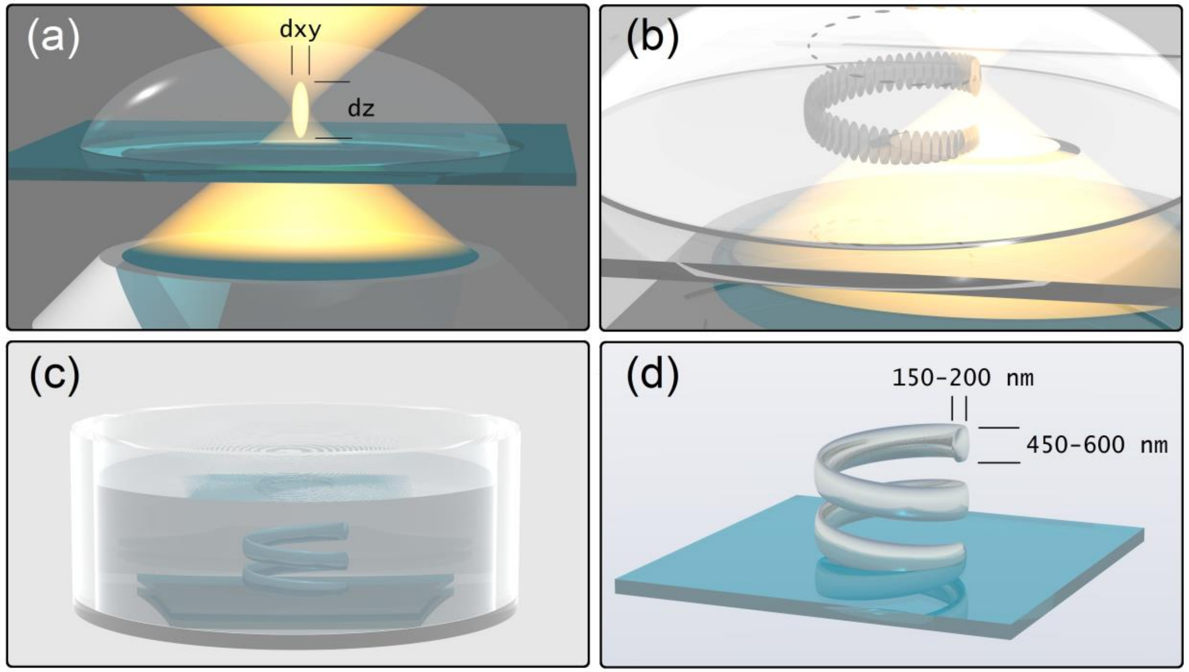
Ultrafast laser processing of materials: from science to industry, Light: Sci. Appl. **5**, e16133 (2016) [NPG].

875 citations!

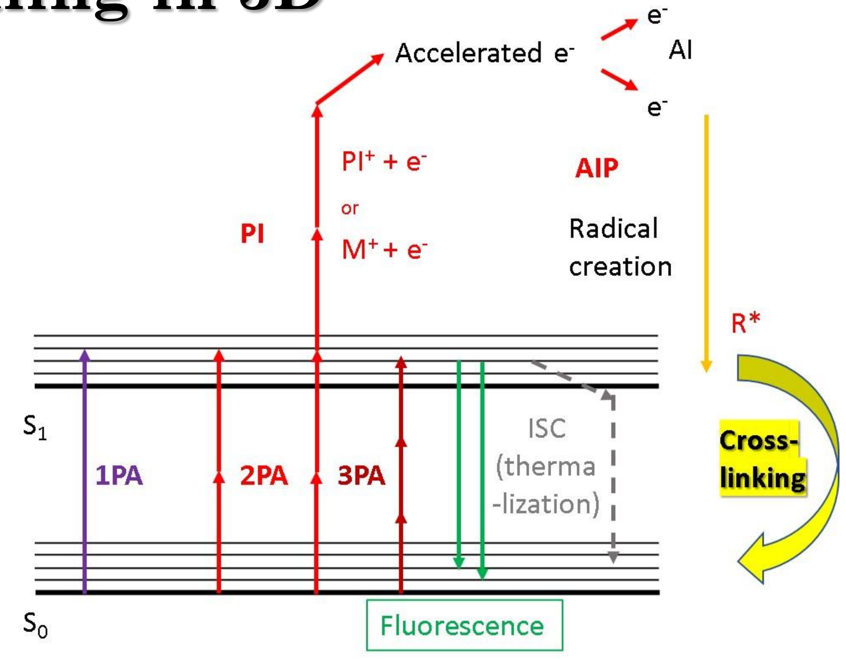
HIGHLY CITED PAPER

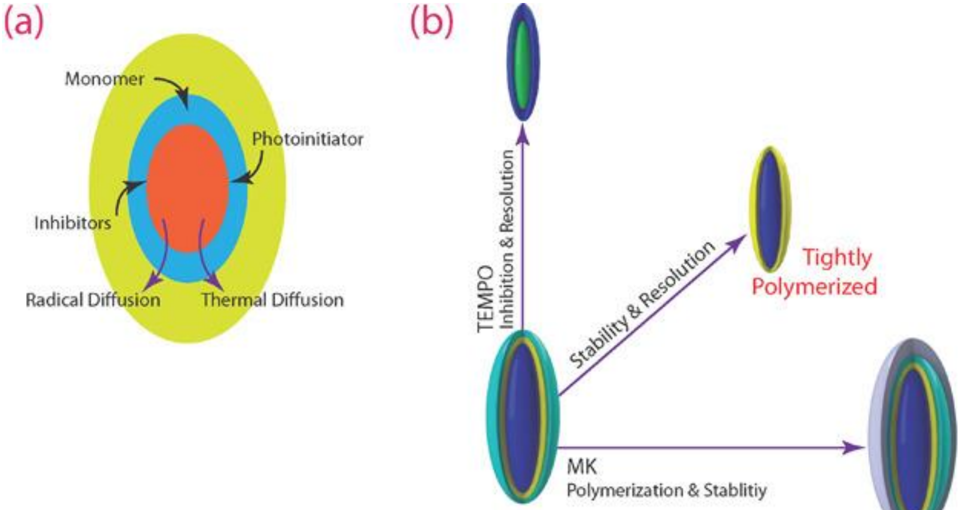
Group Leader: **Prof. Mangirdas Malinauskas**
Researchers: **Dr. Darius Gailevičius, Dr. Sima Rekštytė (on maternity holidays)**
Engineer: **Mr. Arūnas Čiburys**
PhD students: **Edvinas Skliutas, Giedrius Balčas**
Master / Bachelor students: **Karolis Galvanauskas, Jurga Jeršovaitė, Antanas Butkus**

Thresholding and scaling in 3D



S. Varapnickas and M. Malinauskas, *Processes of Direct Laser Writing 3D Nano Lithography*, Handbook of Laser Micro- and Nano-Engineering, **Springer**, 1-31 (2020).





P. Prabhakaran, Y. Son, C.-W. Ha, J.-J. Park, S. Jeon, K.-S. Lee, *Optical Materials Forming Tightly Polymerized Voxels during Laser Direct Writing*, Adv. Eng. Mater. **20**(10), 1800320 (2018).

Controlled photo-physical-chemical mechanisms for unlimited freedom in 3D nanotechnology

Putting it all together: meso-butterfly

Embedded nanolattice

Additive manufacturing:
1.9 x 10^{-3} mm^3/min

NA = 1.4
3.2 x 10^5 voxels/s

Made in: 2.5 hours

Line width **~650 nm**

Jonušauskas, *Opt. Express* **27**, 15205 (2019)

Fabrication

LIGHT CONVERSION

femtika

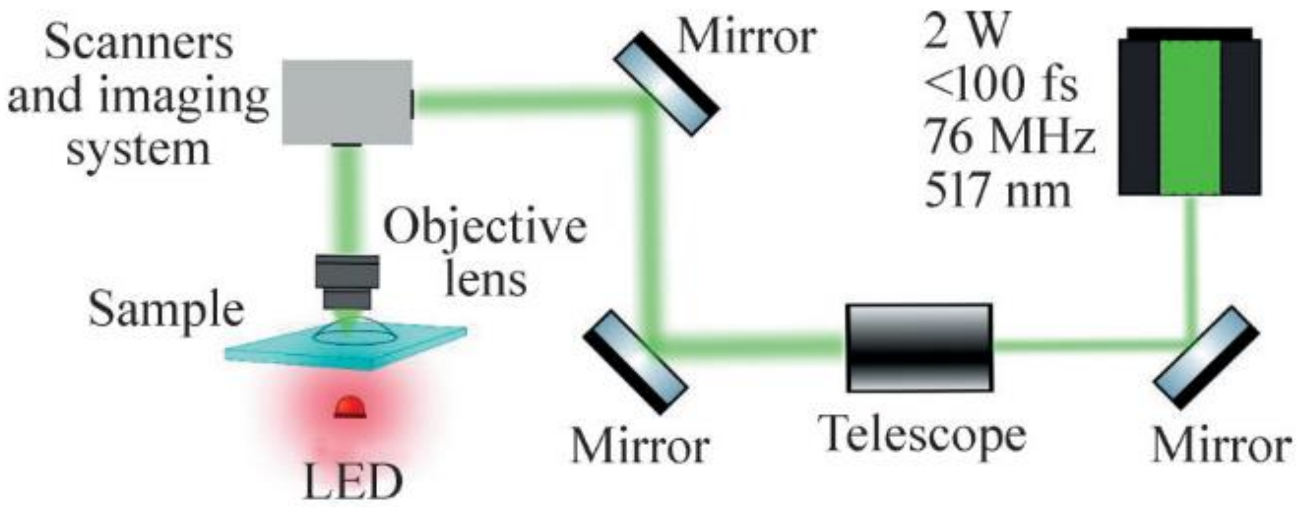


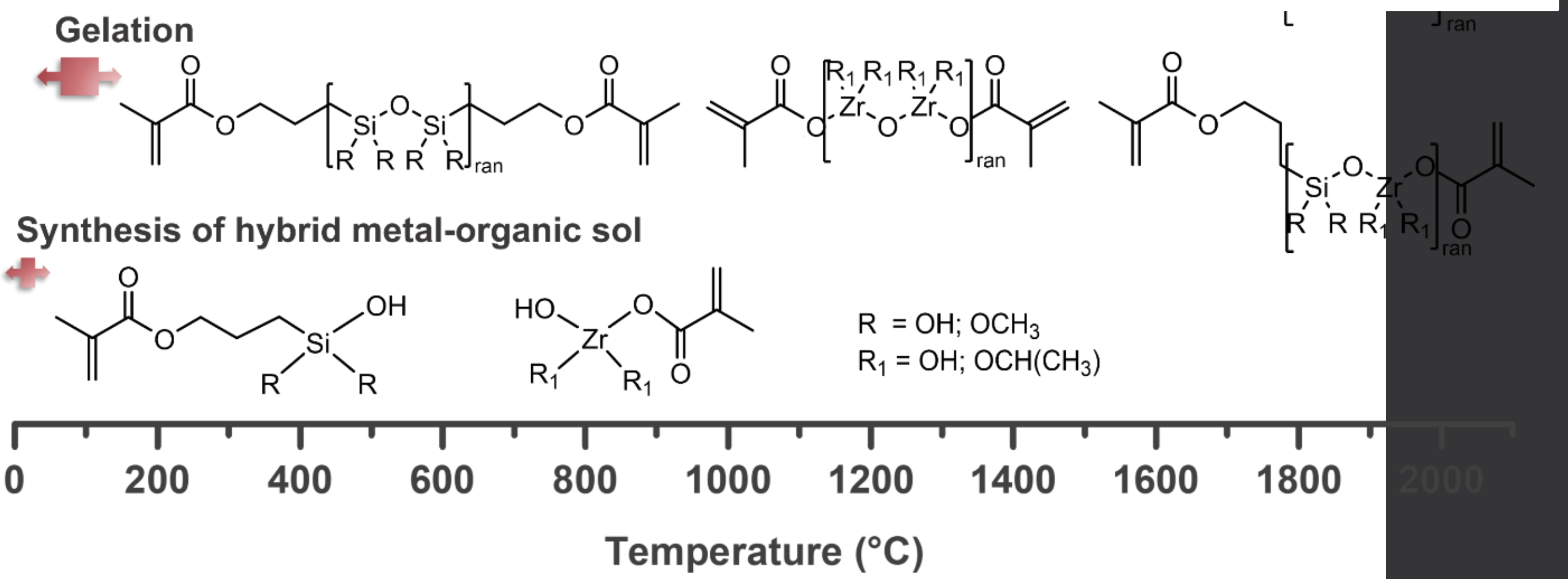
Figure 2 Simplified schematics of the Laser Nanofactory system

63x 1.4 NA $\boldsymbol{v}$ **= 1 mm /s** $\boldsymbol{P}$ **= 5.6 mW**

Butkus, A., Skliutas, E., Gailevičius, D. & Malinauska ... raphy using VIS-light oscillator. *J. Cent. South Univ.* **29**, 32... (2022).

Samsonas, D. *et al.* 3D nanopolymerization and damage threshold dependence on laser wavelength and pulse duration. *Nanophotonics* (2023) doi:10.1515/nanoph-2022-0629.

Concept

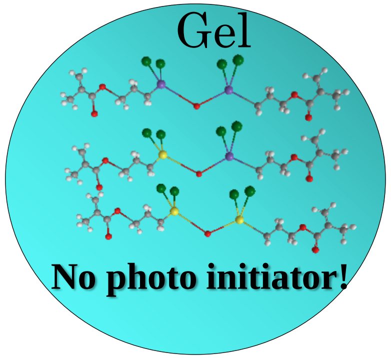


2PP super-powered for 3D nanoprinting of diverse inorganics:

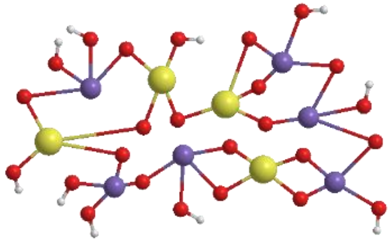
G. Merkininkaite et al., Laser additive manufacturing of Si/ZrO_2 tunable crystalline phase 3D nanostructures, Opto-Electron. Adv. **5**, 210077 (2022); 10.29026/oea.2022.210077

TECHNOLOGY

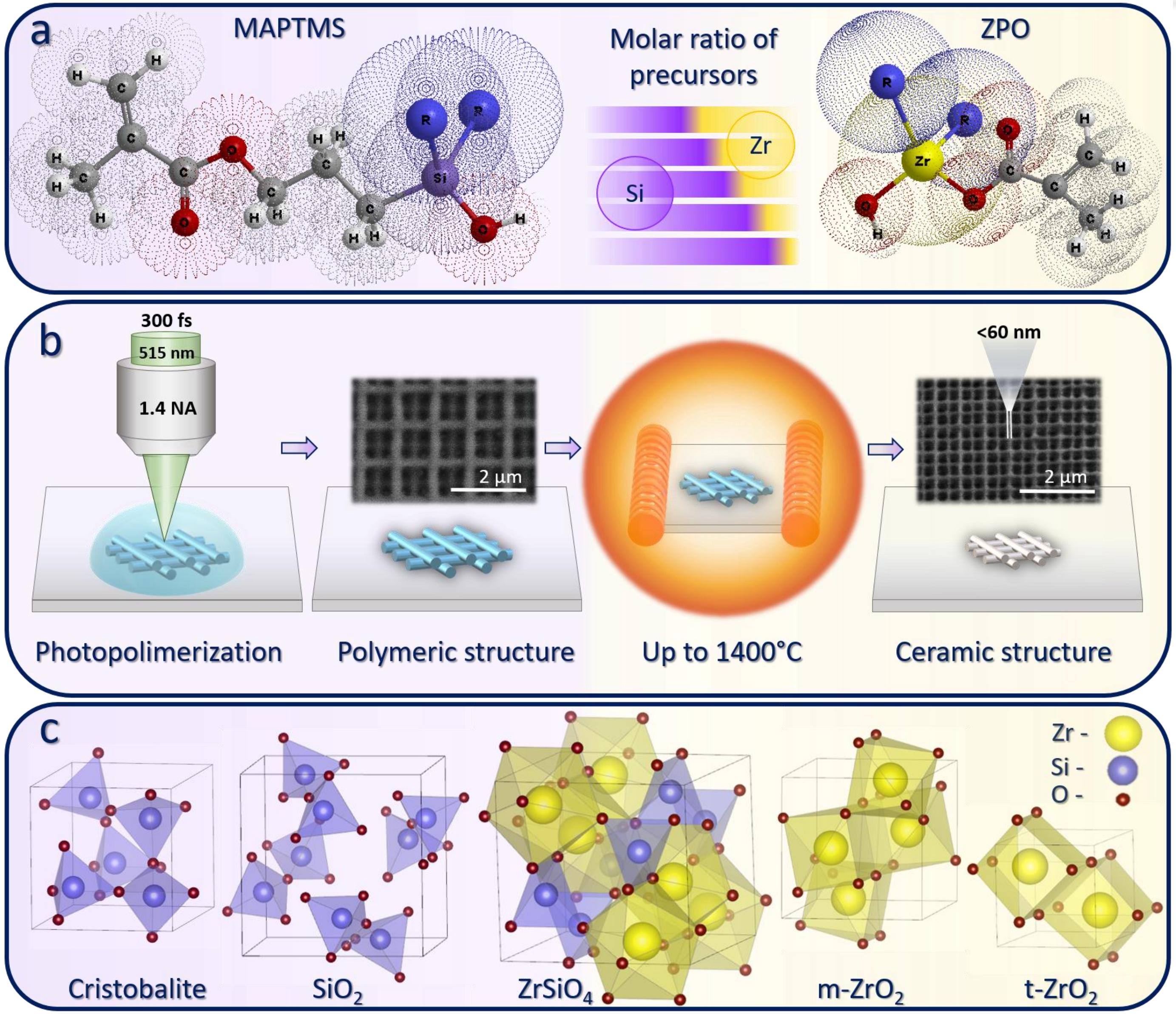
Synthesis



Laser Writing

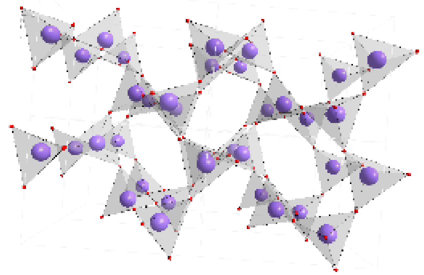


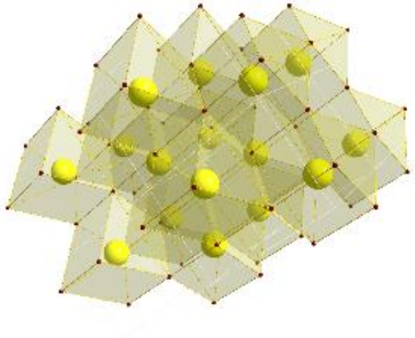
Heat Treatment



Cristabolite – exotic material;
$ZrSiO_4$ – diamond like (hard);
t-ZrO_2 – abrasion resistant;
m-ZrO_2 – biomaterial.

Amorphous glass

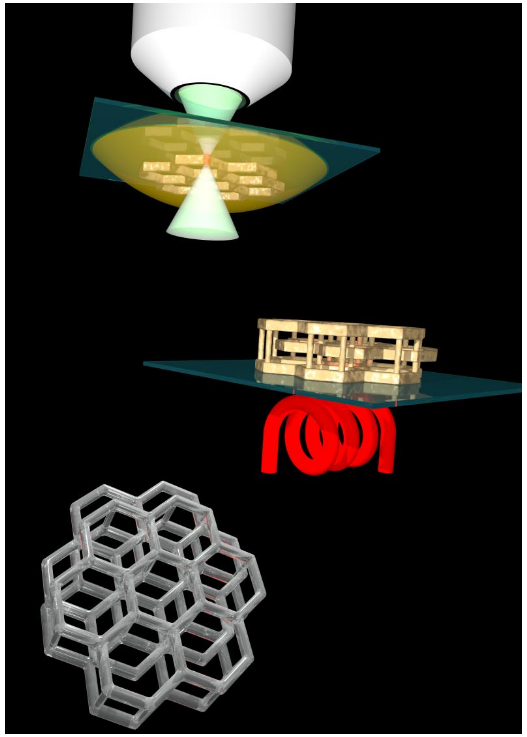


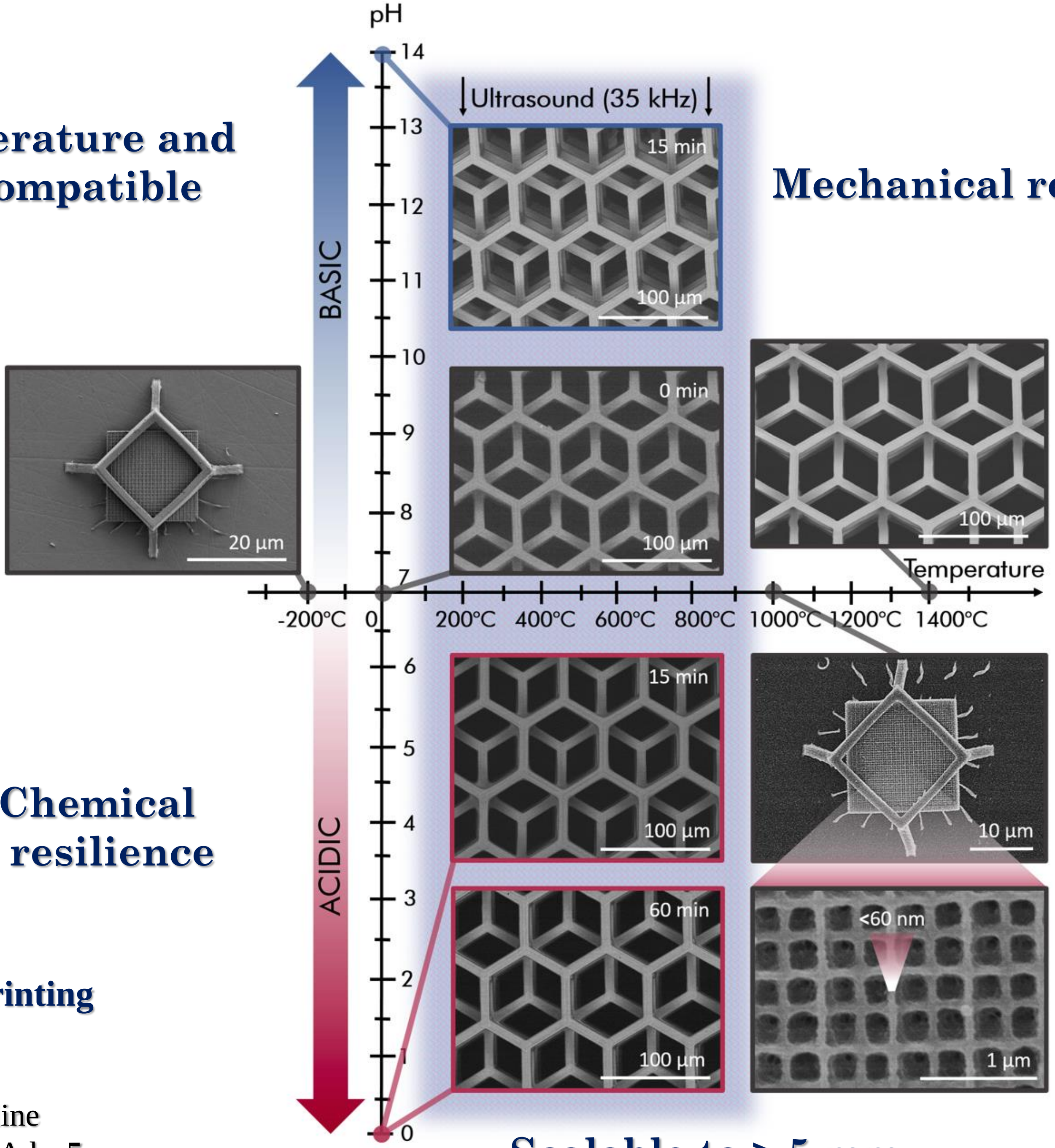


Crystalline ceramic

G. Merkininkaitė et al., accepted to Opto-Elect. Adv, Preprints **2020120707**, (2020): 10.20944/preprints202012.0707.v1.

Low temperature and vacuum compatible





Mechanical resilience

Temperature resistant to > 1000 – 1400 °C

Chemical resilience

Ultra-high precision: Features of 60 nm

Scalable to > 5 mm

2PP super-powered for 3D nanoprinting of diverse inorganics:

G. Merkininkaite et al., Laser additive manufacturing of Si/ZrO_2 tunable crystalline phase 3D nanostructures, Opto-Electron. Adv. **5**, 210077 (2022); 10.29026/oea.2022.210077

$\tau = 300$ fs
$\lambda = 515$ nm
$\nu = 200$ kHz

Microscope objective: 63x 1.4 NA (oil immersion)
$v = 500$ µm/s
$I =$ from 0.23 to 0.37 TW/cm^2

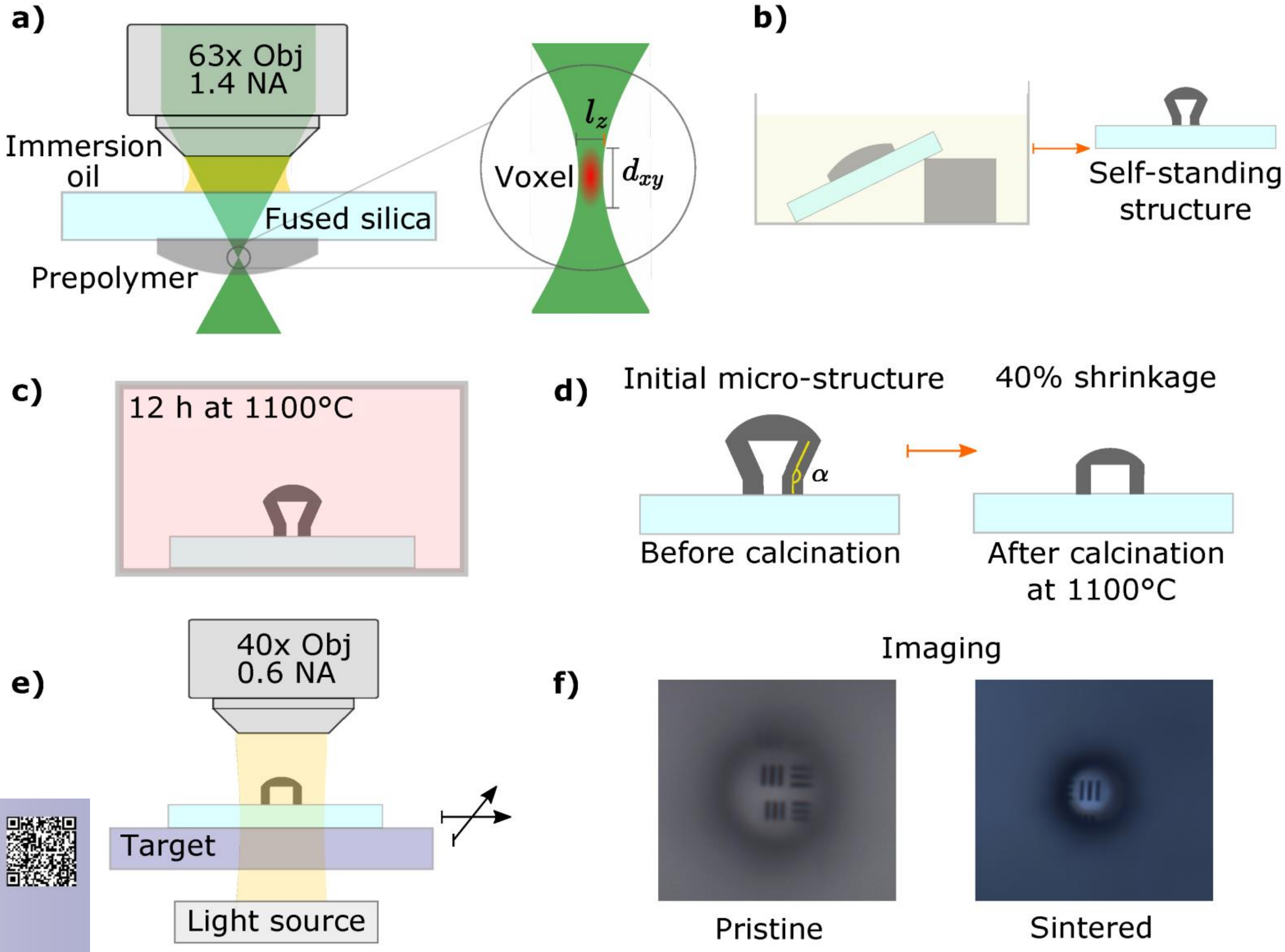
$T = 1100$ °C
$t = 12$ h.

photonics
an Open Access Journal by MDPI

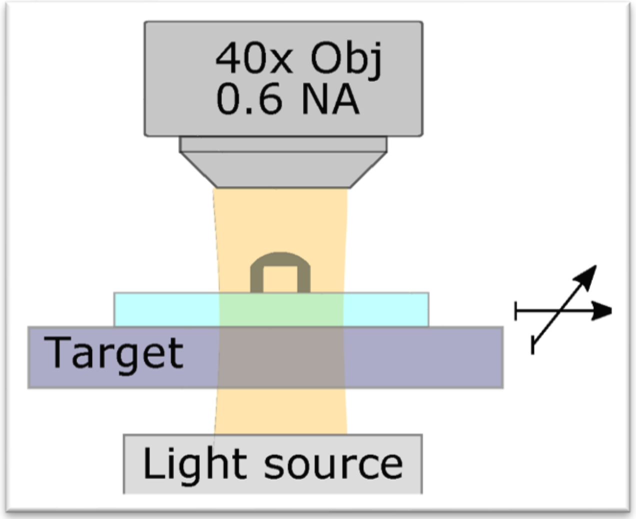
Laser 3D Printing of Inorganic Free-Form Micro-Optics

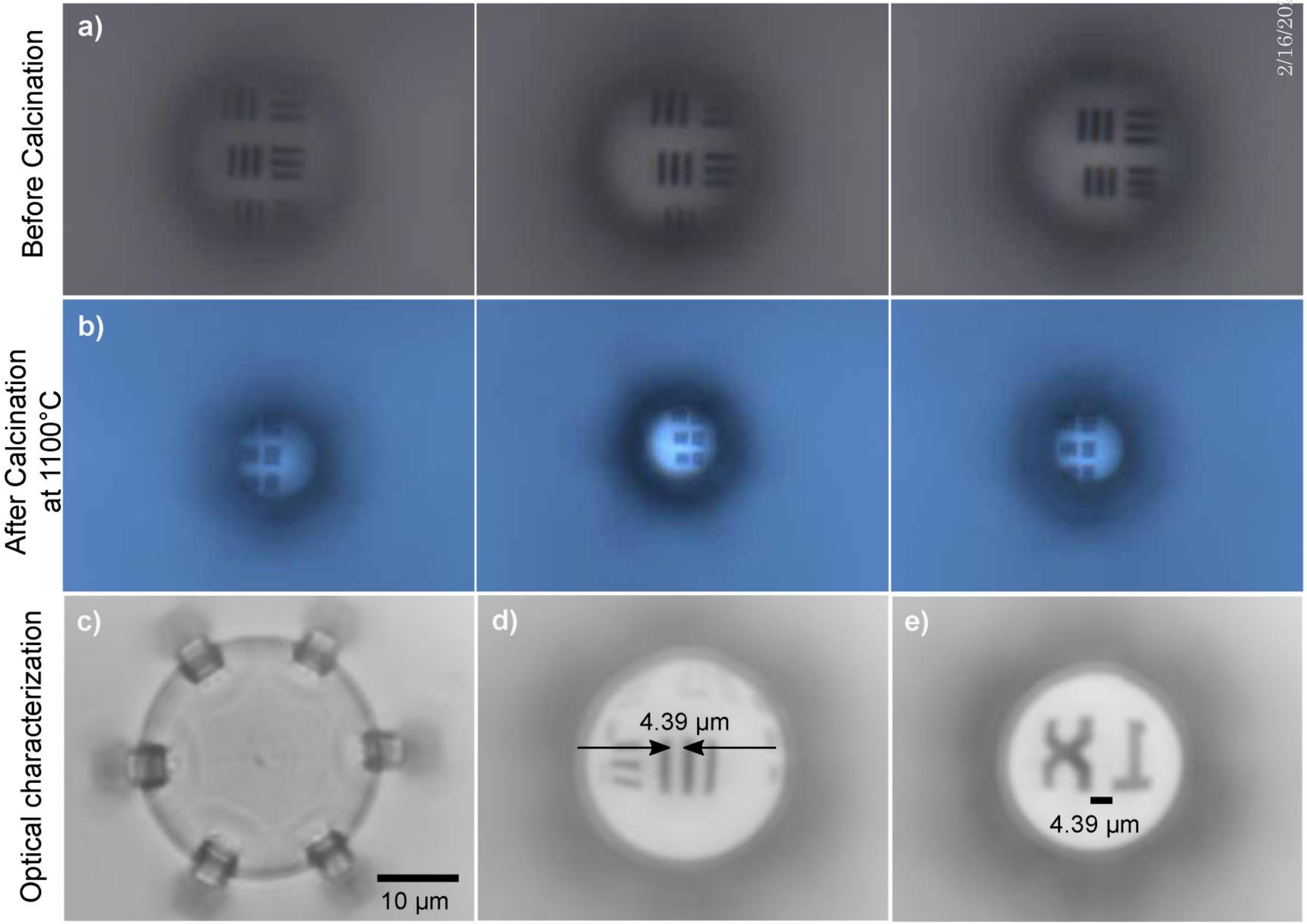
Diana Gonzalez-Hernandez; Simonas Varapnickas; Greta Merkininkaitė; Arūnas Čiburys; Darius Gailevičius; Simas Šakirzanovas; Saulius Juodkazis; Mangirdas Malinauskas

Photonics 2021, Volume 8, Issue 12, 577



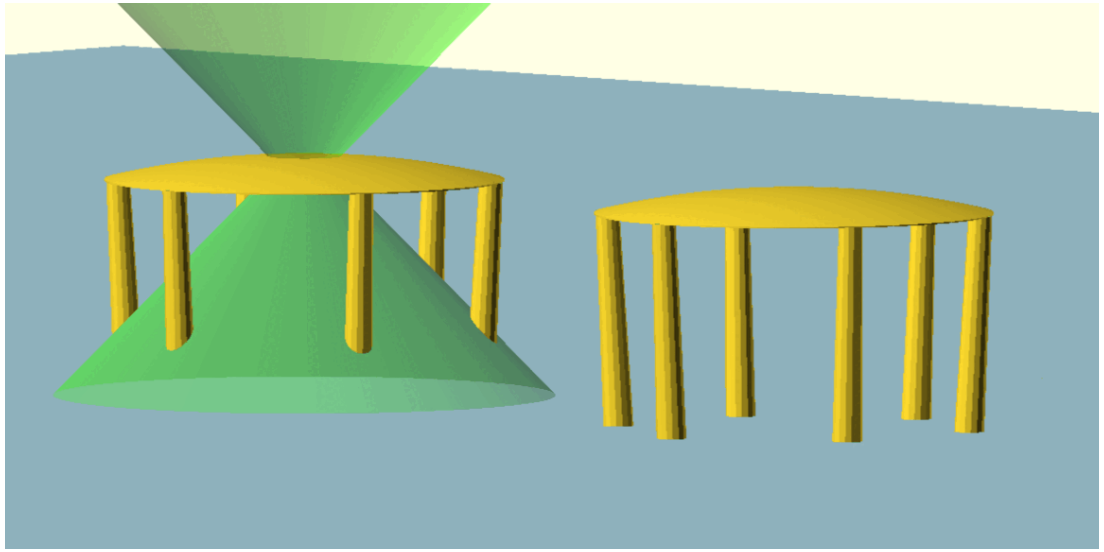
Imaging performance



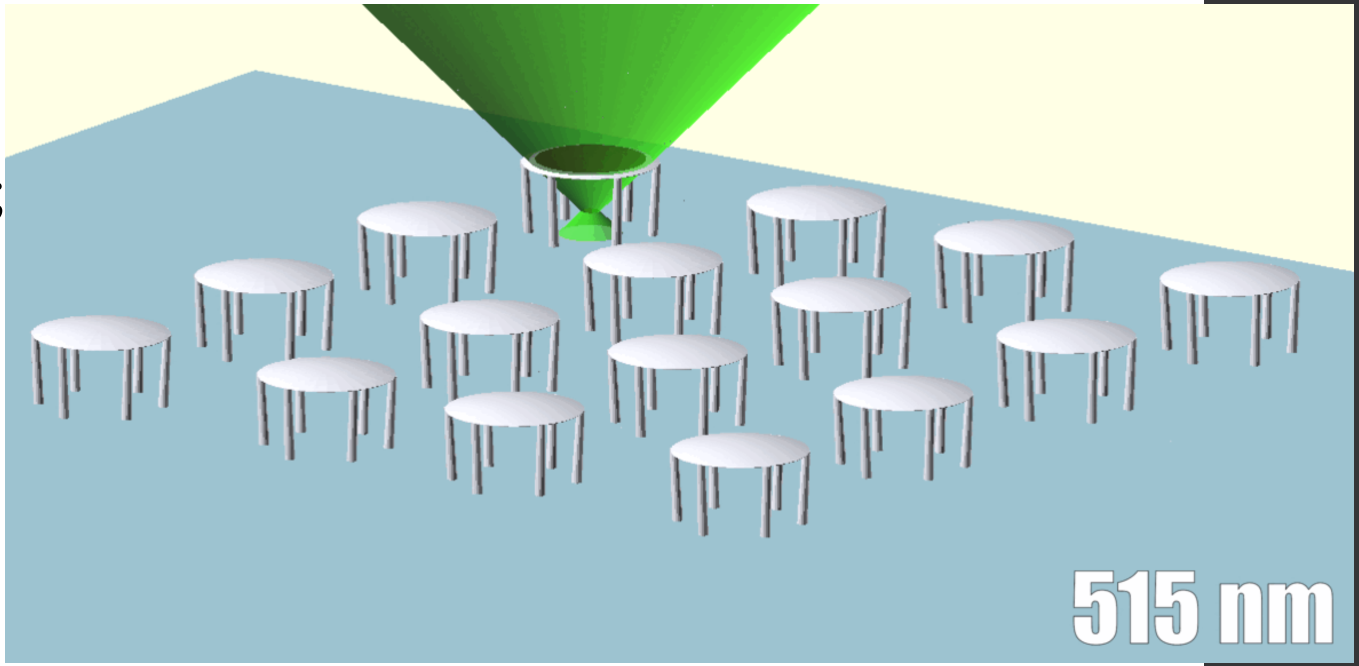


Laser-induced damage threshold

- Localized damage (4 µm);
- Non-localized damage (up to 20 µm);



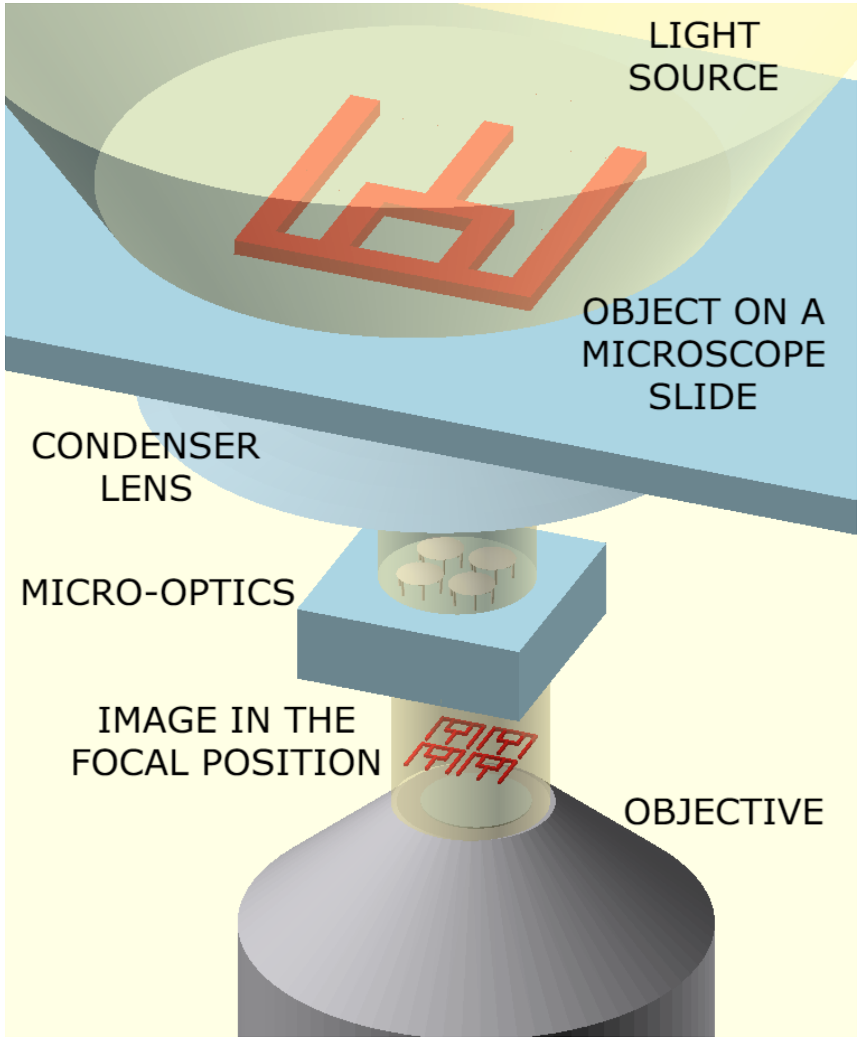
Optical damage experiment principle



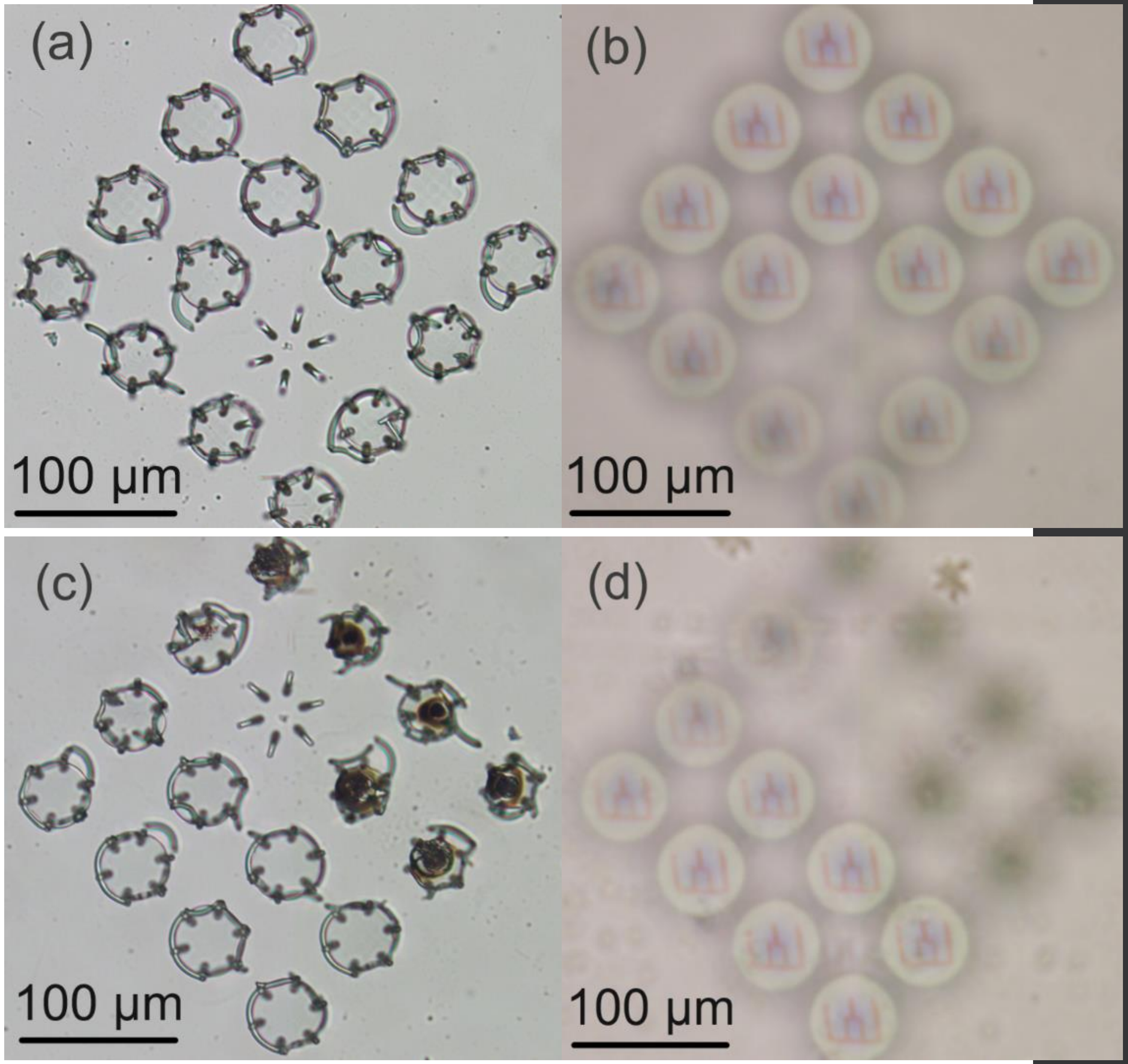
S-on-1 Laser damage setup

$$\lambda = 1030, 515\ nm$$
$$f = 200\ kHz$$
$$t = 300\ fs$$
$$Objective\ 20x\ NA = 0.8$$
$$50\ ms - 5\ s\ exposure$$
$$Localized\ - 4\ \mu m\ diameter\ 1/e^2$$
$$Nonlocalized\ - 20\ \mu m\ diameter\ 1/e^2$$

Optical quality



Setup of an inverted microscope for micro-optic imaging

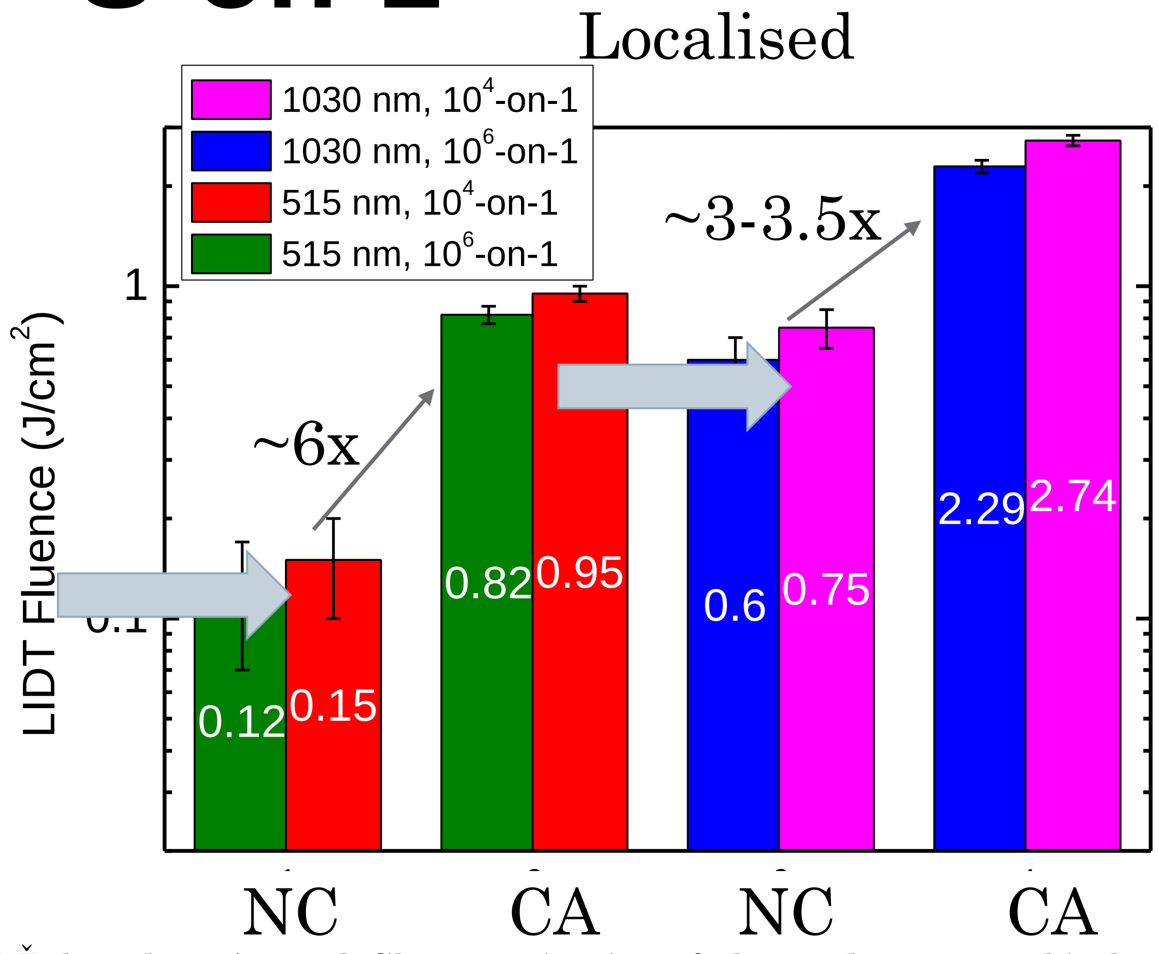


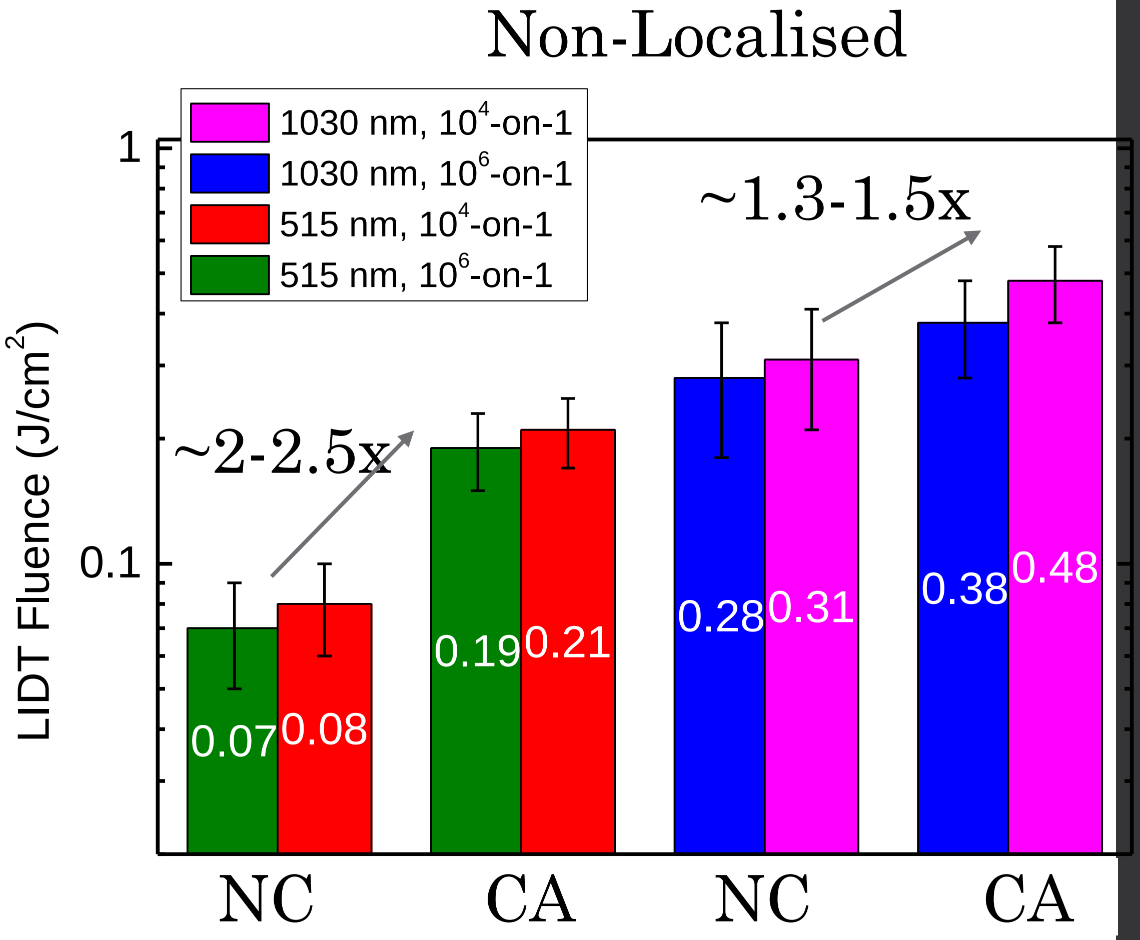
Micro-lenses and images before and after laser damage

LIDT results S-on-1

$\lambda = 1030, 515\ nm$
$f = 200\ kHz$
$t = 300\ fs$
$Objective\ 20x\ NA = 0.8$

$50\ ms/5\ s\ (10^4\text{-on-1})/(10^6\text{-on-1})$
$Localized\ - 4\ \mu m\ diameter\ 1/e^2$
$Nonlocalized\ - 20\ \mu m\ diameter\ 1/e^2$

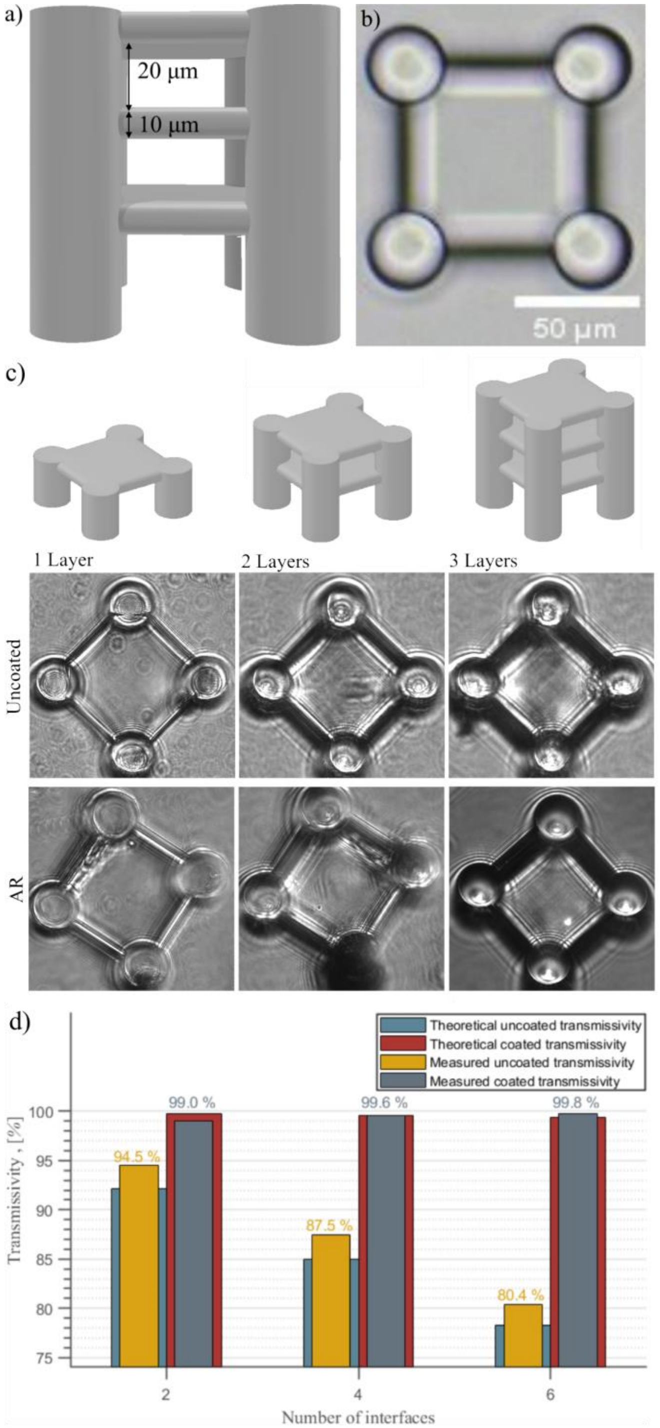




[1] Žukauskas, A. *et al.* Characterization of photopolymers used in laser 3D micro/nanolithography by means of laser-induced damage threshold (LIDT). *Opt. Mater. Express* **4**, 1601 (2014).

[2] Žukauskas, A. *et al.* Effect of the photoinitiator presence and exposure conditions on laser-induced damage threshold of ORMOSIL (SZ2080). *Opt. Mater. (Amst).* **39**, 224–231 (2015).

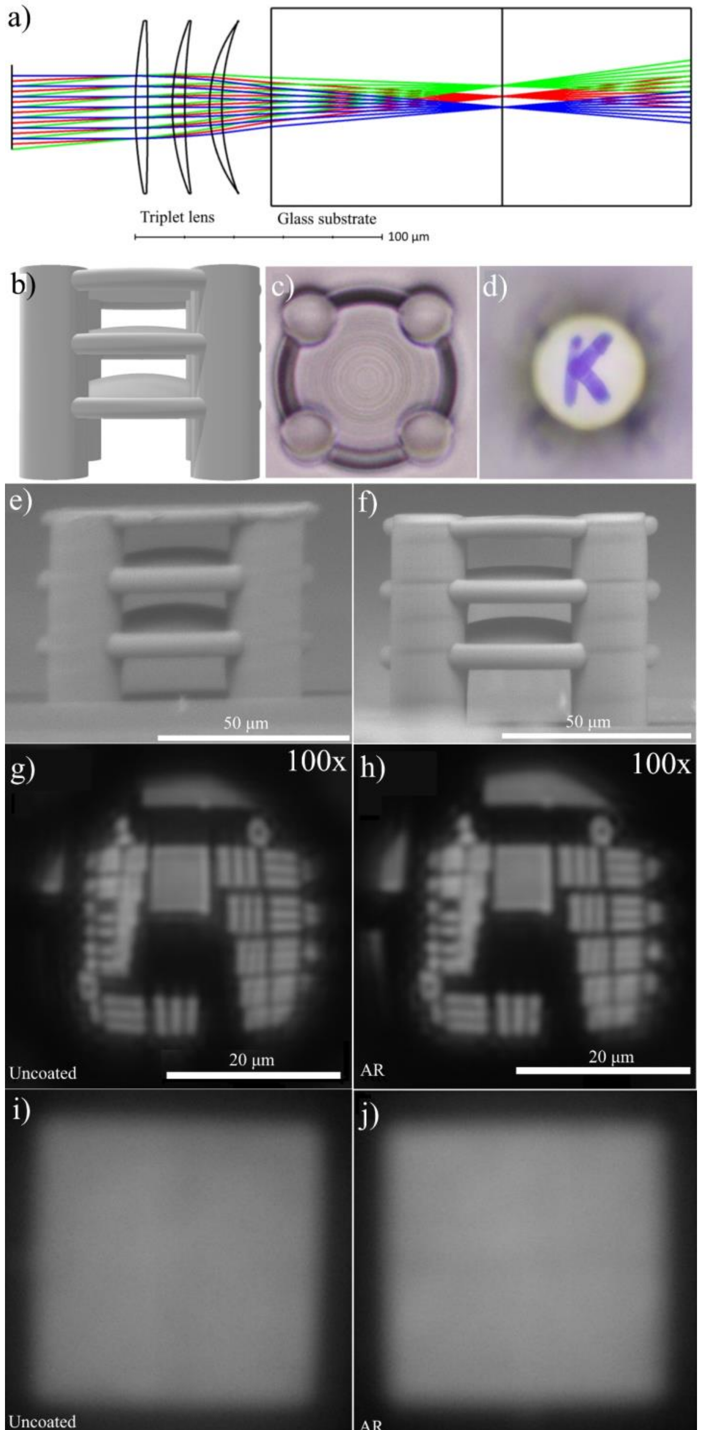
[3] Butkutė, A. *et al.* Optical damage thresholds of microstructures made by laser three-dimensional nanolithography. *Opt. Lett.* **45**, 13 (2020).



There are no conclusions, just ongoing work – atomic layer deposition of anti-reflective coatings on 3D micro-optics.

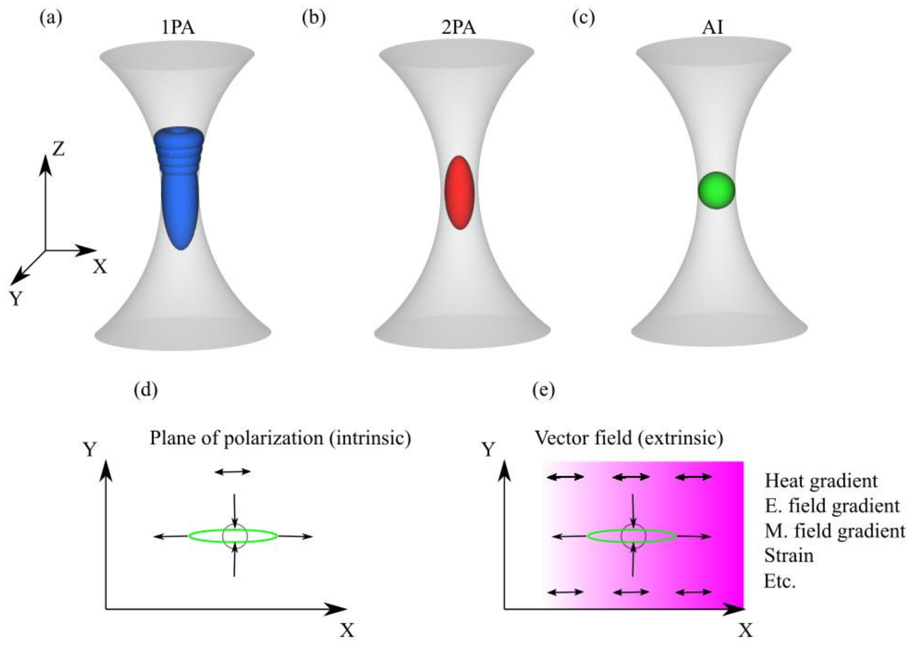
ALD deposited 154 nm aluminum and titanium oxide AR coating (comprising of 23 nm TiO_2 and 131 nm Al_2O_3) on SZ2080^{TM} produces a substantial improvement in transparency - up to 99.9% per interface in the case of flat platforms and1 0% compound improvement of a complex triplet objective. 30-fold reduction of Fresnel reflection losses has been achieved.

Anti-reflective thin film, layers was modeled for the lowest reflectivity at λ=633 nm.



My time is over, but not Yours ;-)

- Questions?
- Comments!
- Discussions..



mangirdas.malinauskas@ff.vu.lt