

Femtosecond laser-based manufacturing of functional 3D objects: from nanoresolution to millimeter size devices

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30 January, 2020

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Laser companies in Lithuania



The number of **companies** developing and producing lasers, laser solutions and services in **Lithuania** - >4 times growth in 10 years!

Femtika joined Lithuania laser community in 2013 and employed 6 specialists

2009
>430

The number of **employees** expanded more than twice!

2019
>1130

>2% of all Lithuania laser industry employees work at **Femtika**





ELI project

ELI Beam Lines L4 (Czech Republic, Prague)
Most powerful femtosecond laser in a world!

Laser "CERN"

Finish: 2018

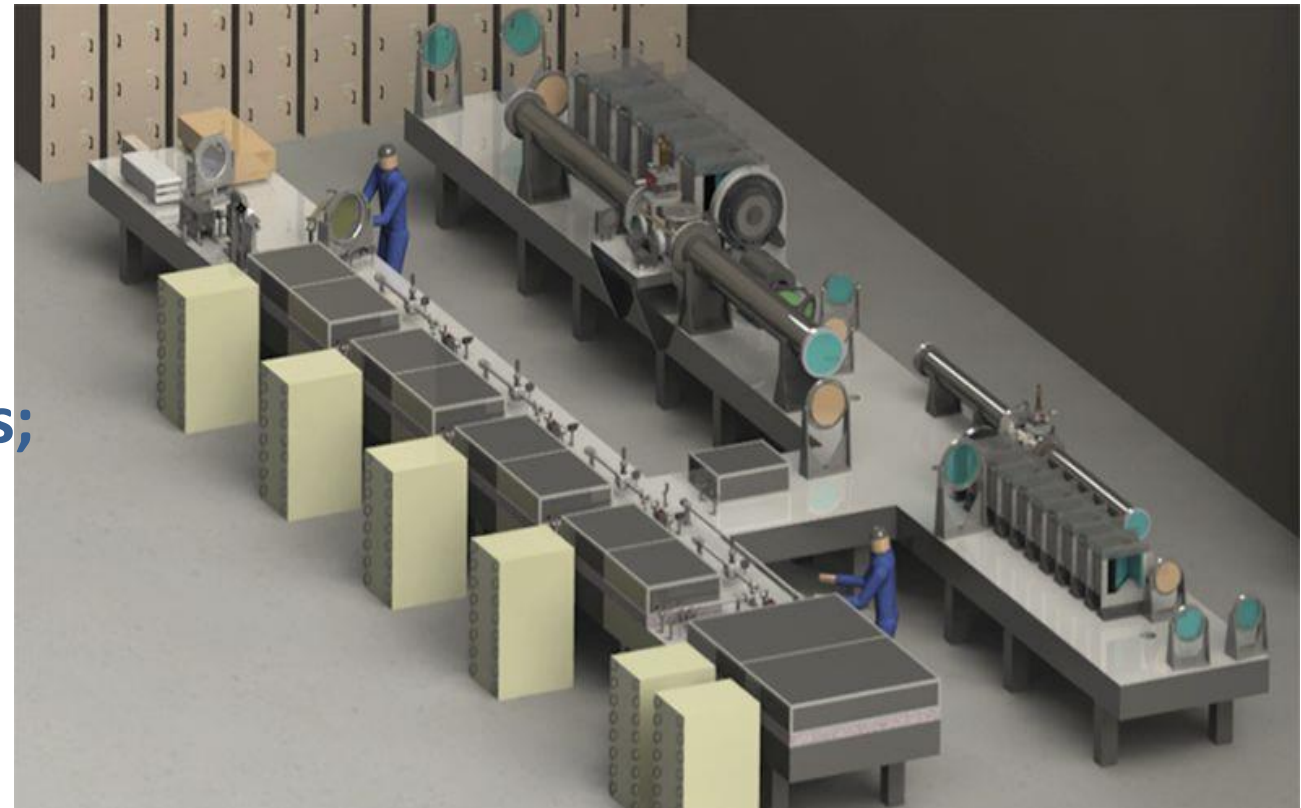
10 PW;

• **Technology:**

Split disc mixed glass amplifiers;

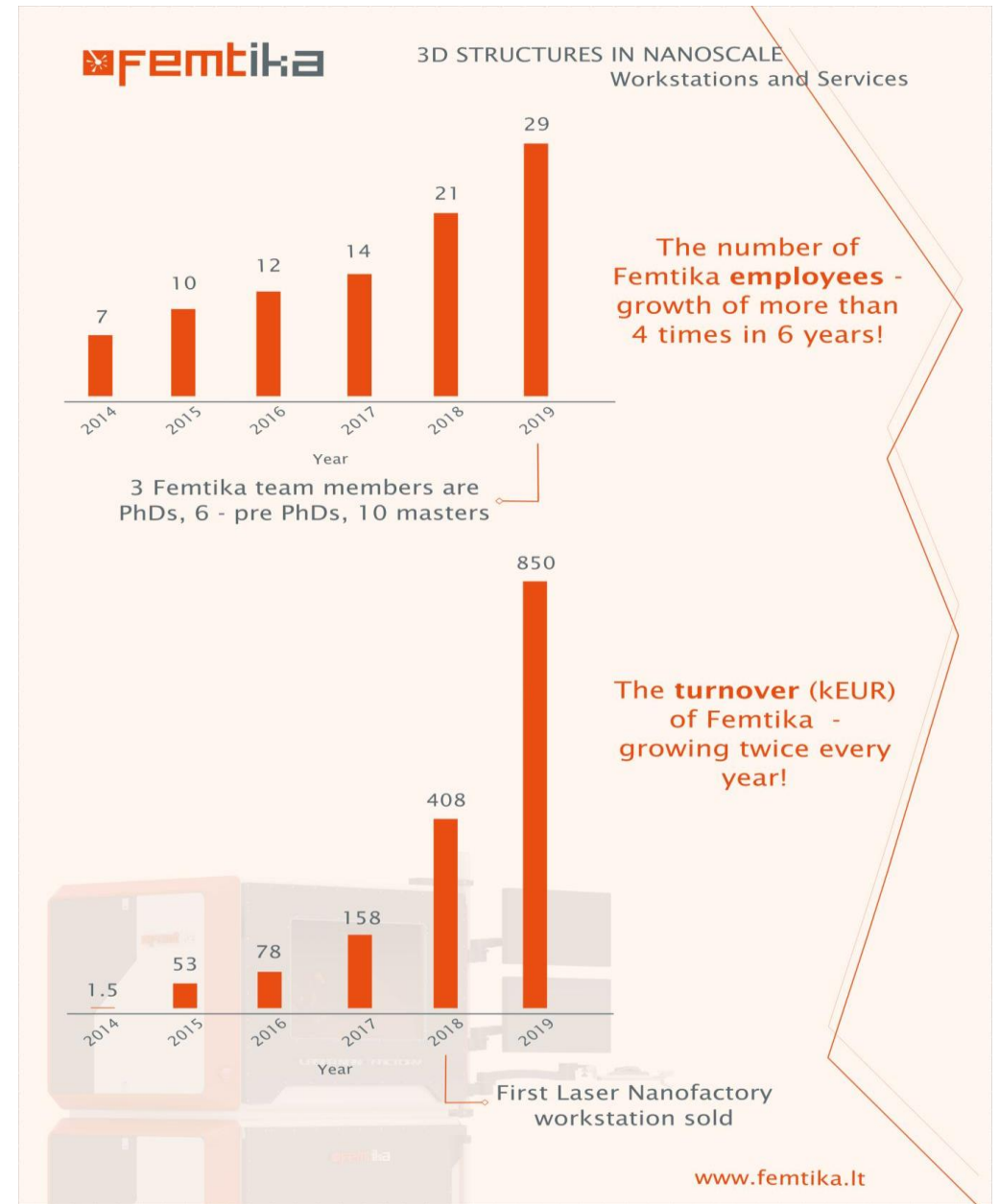
• **Pulse duration 150 fs;**

• **Pulse energy 1500 J.**



Femtika is a spin-off from Vilnius University Laser Research Center, working in the area of **laser micro-machining, polymerization and optics solutions:**

- Founded in 2013.
- Employees: 29 (3 PhD, 6 pre PhD).
- Member of Lithuanian Laser Association, EPIC.
- Partners - Light Conversion, Vilnius University, Innovative Medical Center.
- Working in various R&D projects with EU partners (under H2020, Eurostars).



Our product : Laser Nanofactory!

Hybrid micro-fabrication workstation



- All-in-one package;
- Highly tunable;
- Subtractive and additive manufacturing;
- Fast (up to cm/s translation velocity);
- High precision (up to tens of nm) with high working volume (11x11x6 cm³);
- Durable (years of continuous use);

**Enabler of rapid hybrid
subtractive-additive
fabrication of 3D meso-scale
structures!**

Laser Nanofactory – micro-fabrication system

Amplified fs laser allows to combine **additive** and **subtractive** manufacturing.

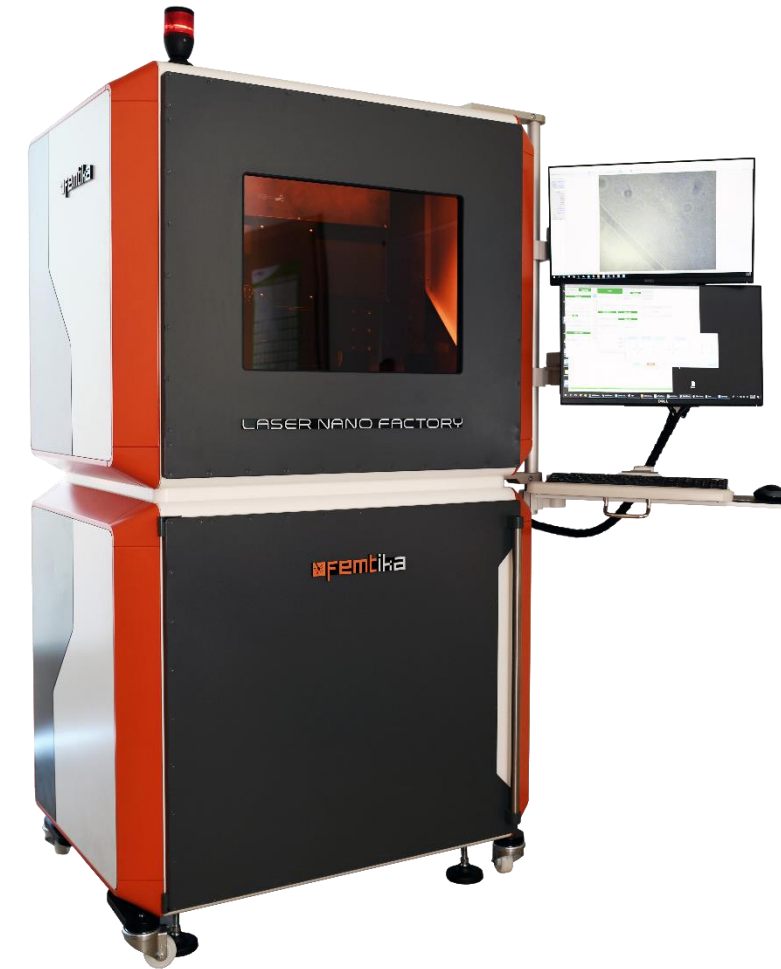
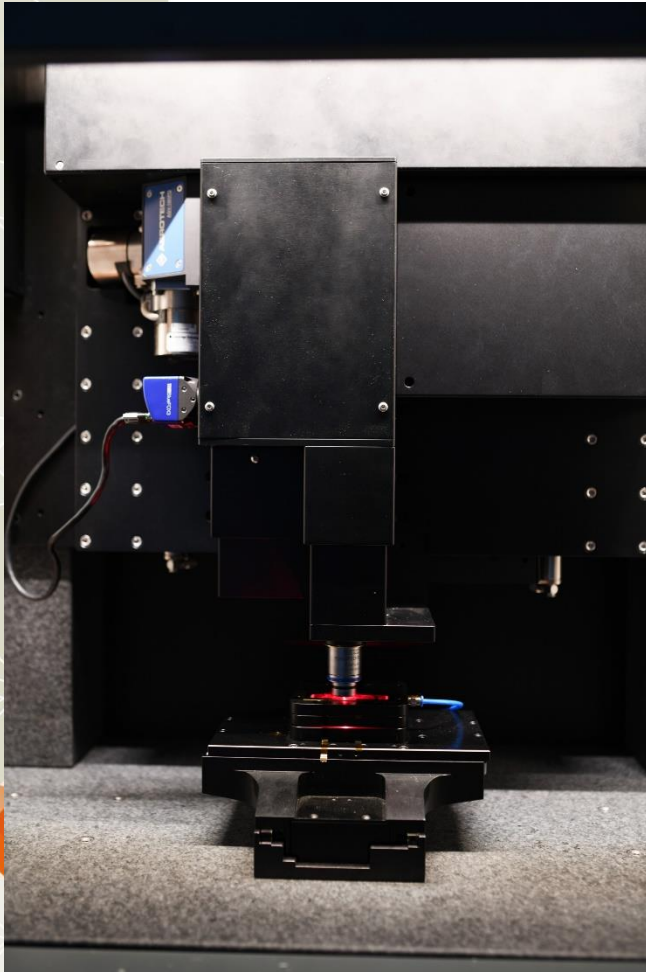
Wide tunability enables efficient fabrication of micro-nano structures using **huge range of materials** (polymers, glasses, metals, ceramics, etc.).

Simultaneous motion of galvo and servo axes over the **entire working field**.

Femtika's own software 3DPoli for the full control of related devices (both manual and from user defined scripts).

Add-ons (for instance optical-fiber holders) and is **customizable** (as a versatile optical characterization setup).

System is **modular, can be adjusted** under requirements and integrated into automatic production line.



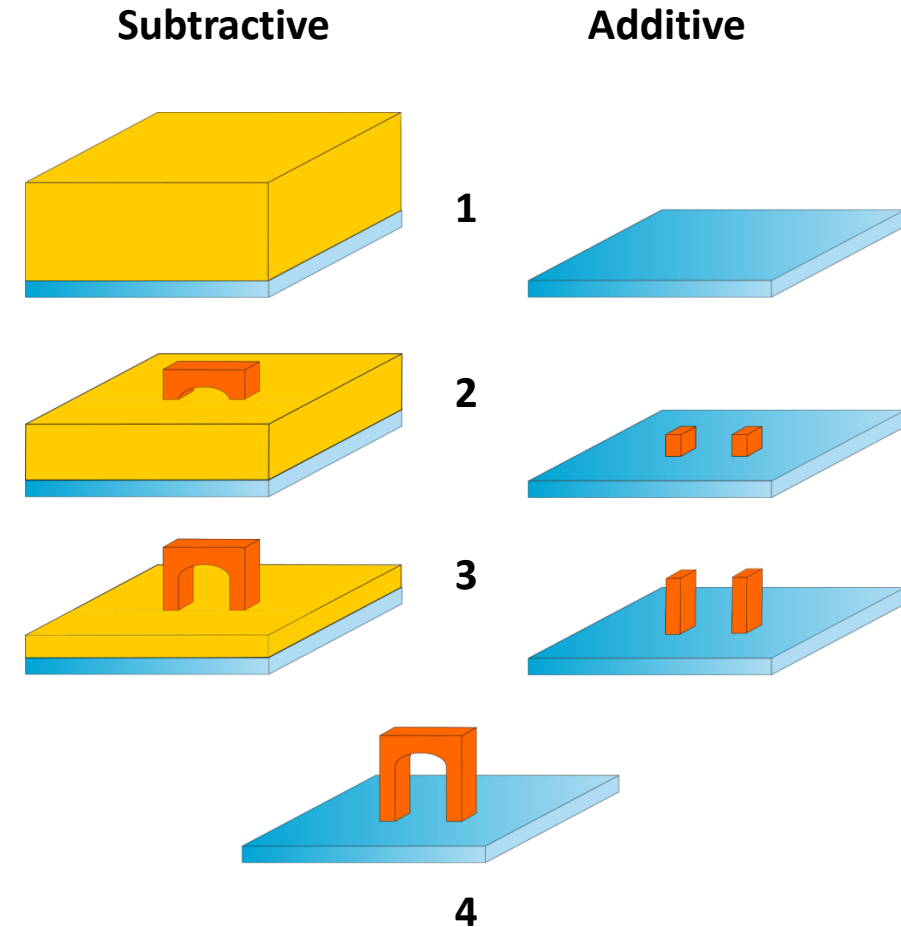
Subtractive vs additive manufacturing

Subtractive:

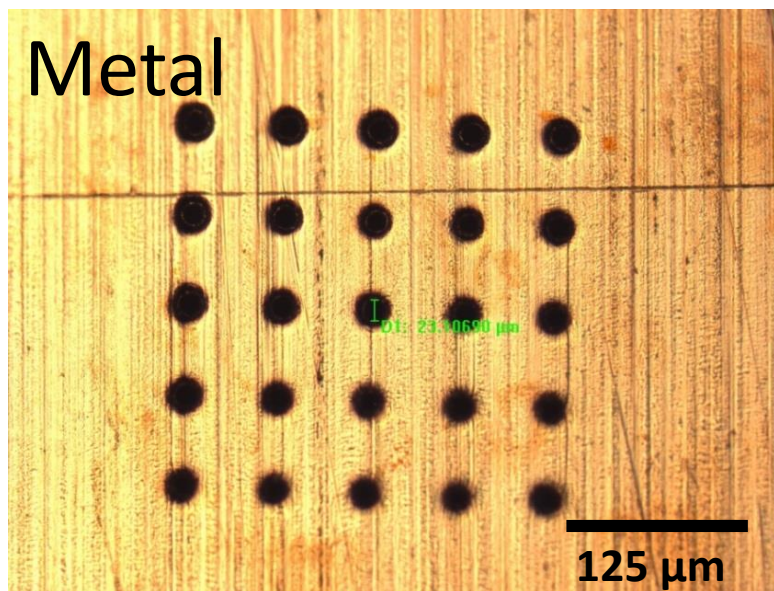
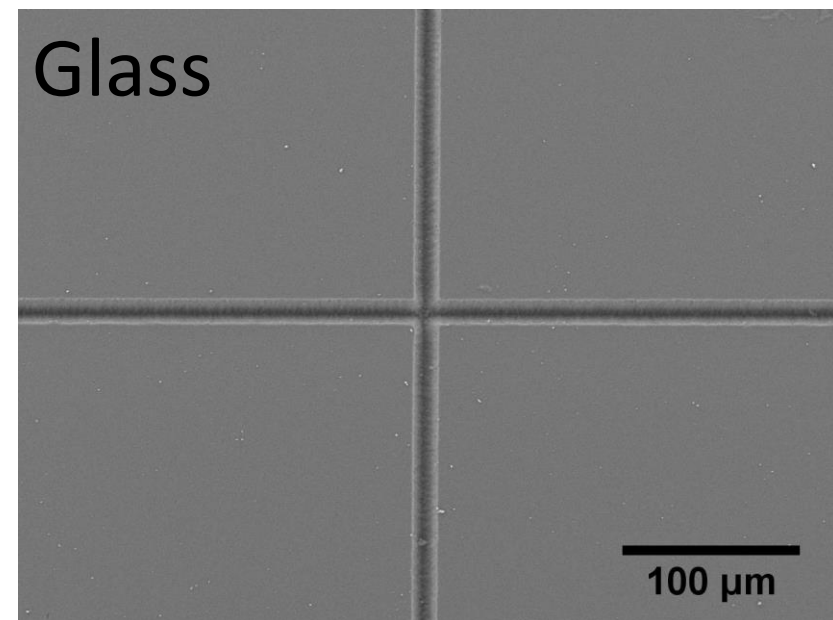
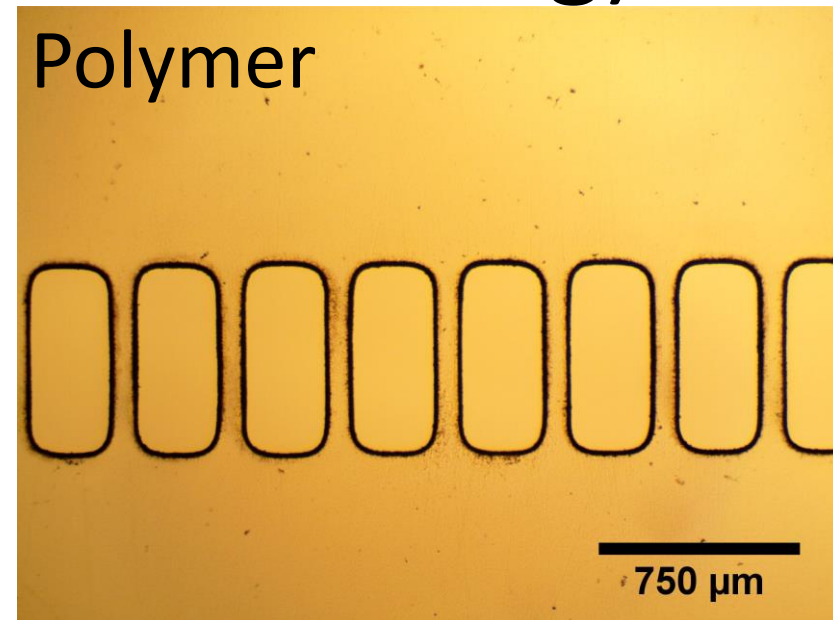
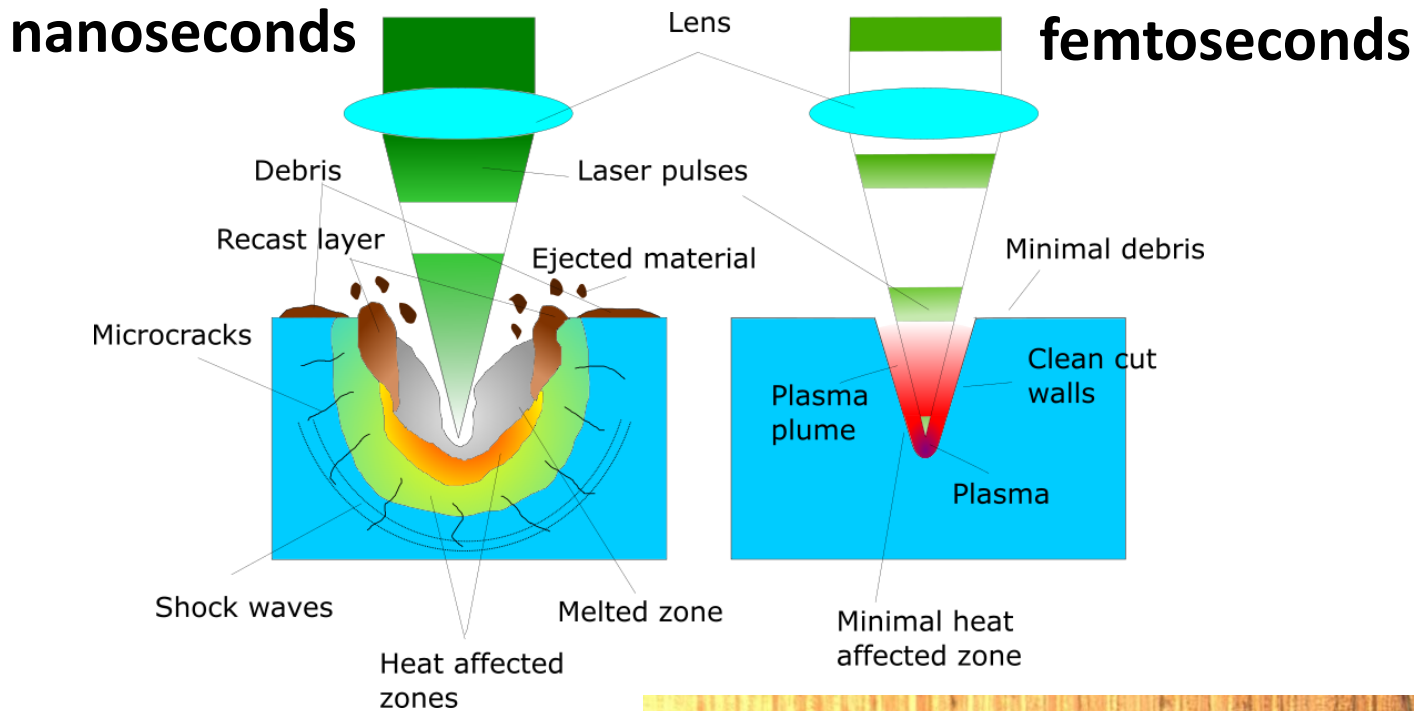
- Examples: CNC machining, laser cutting;
- Relatively faster;
- Simpler;
- No limitations for the materials;

Additive:

- Examples: casting, 3D printing;
- Allows more complex (3D) geometries;
- Low waste;
- Relatively easier structure integration;

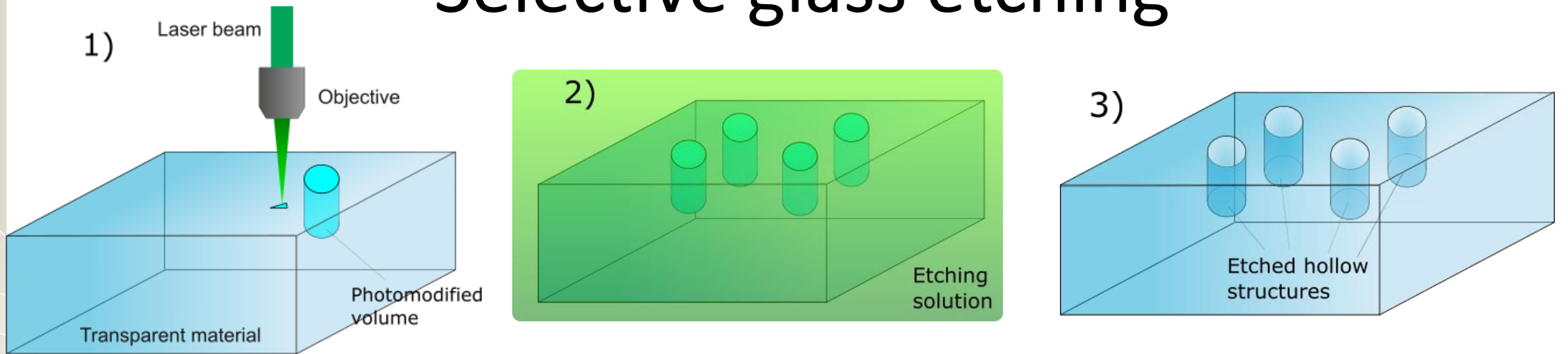


Cold processing (Ablation and drilling)



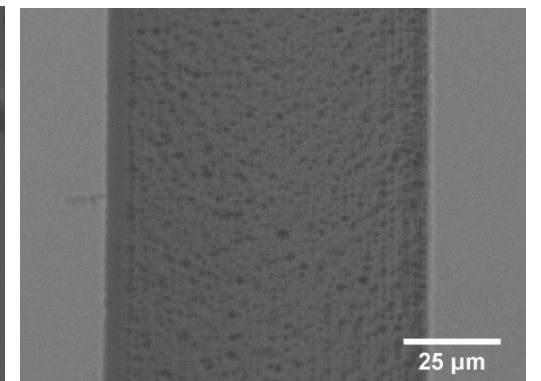
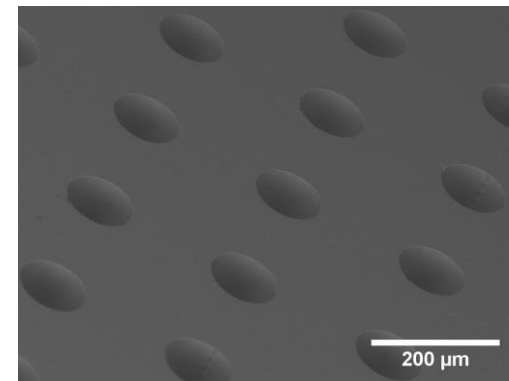
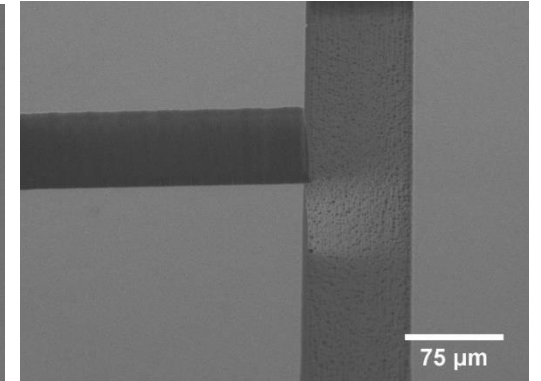
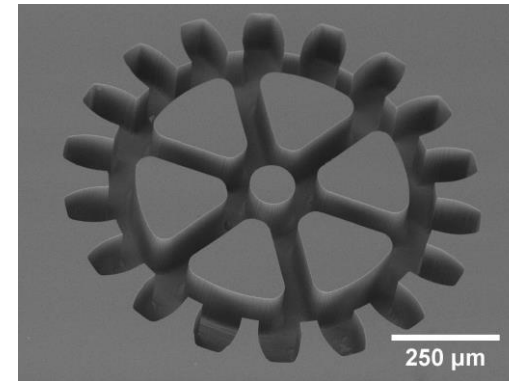
- Low thermal effect;
- High cut quality;
- Simple;
- Fast;
- Applicable to all materials.

Selective glass etching



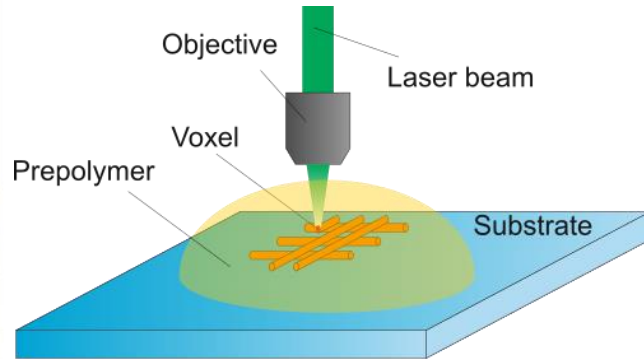
Possibilities:

- Arbitrary **3D shape**;
- Relatively **high surface quality** ($1\ \mu\text{m}$ RMS);
- **Fast fabrication**;
- Possibilities for **large structures** ($\sim\text{cm}$).

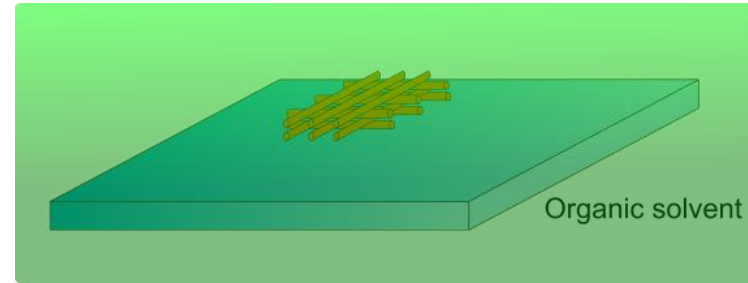


Femtosecond laser 3D lithography

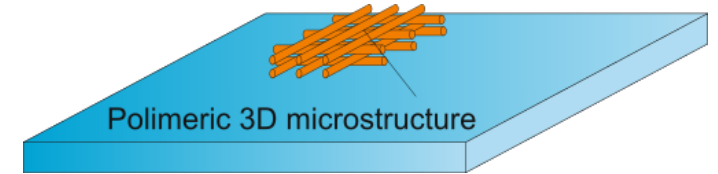
(a) Laser writing



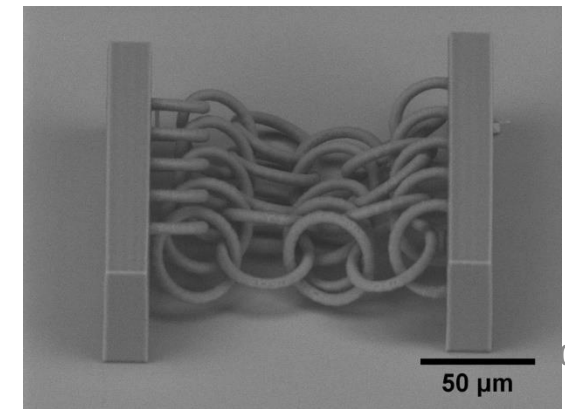
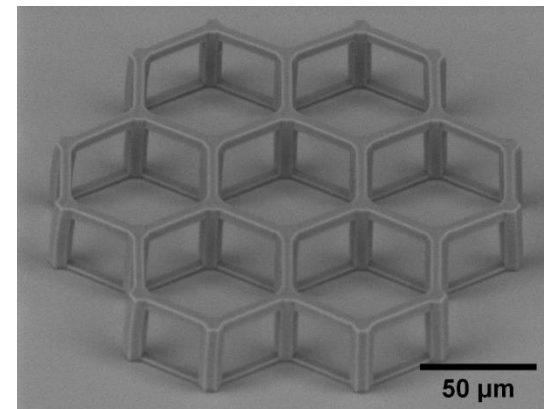
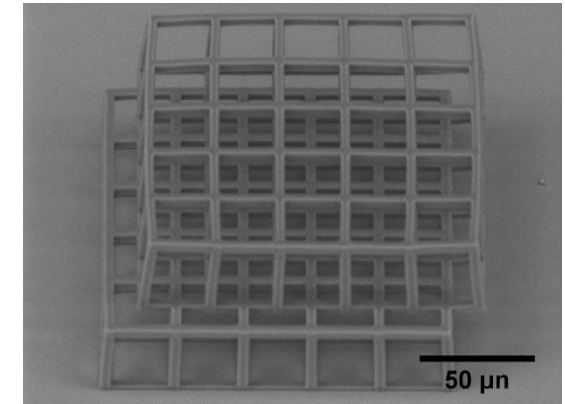
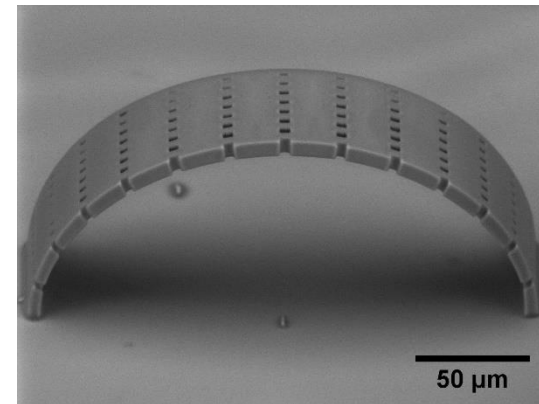
(b) Development



(c) Finished structure

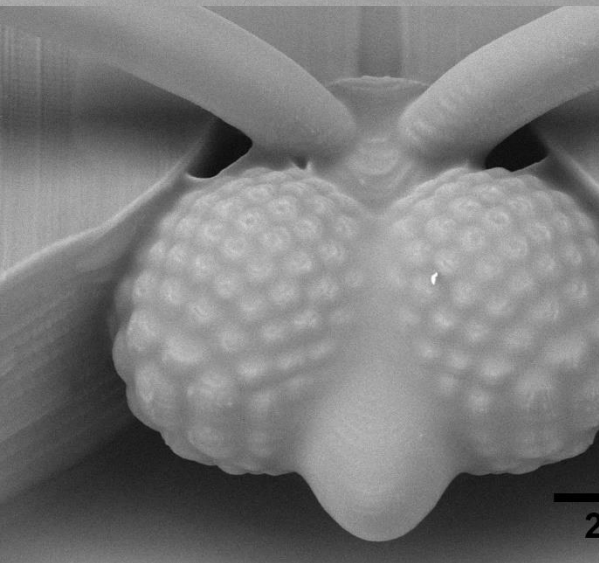
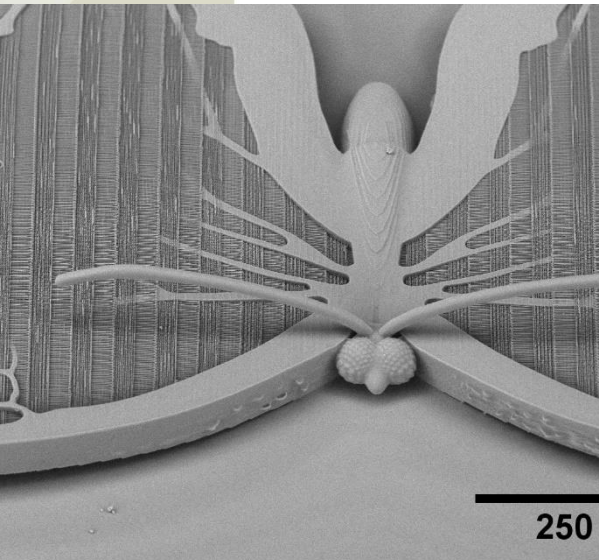


- **Unlimited 3D** architecture;
- Ultra-high spatial **resolution** (<100 nm);
- **Wide variety of materials** (proteins, hydrogels, acrylates, silicon elastomers, hybrid organic-inorganic materials);
- **Flexible and easily tunable.**



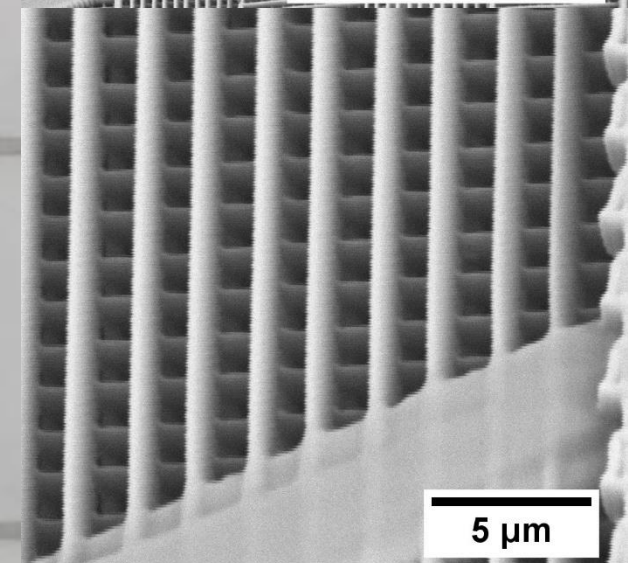
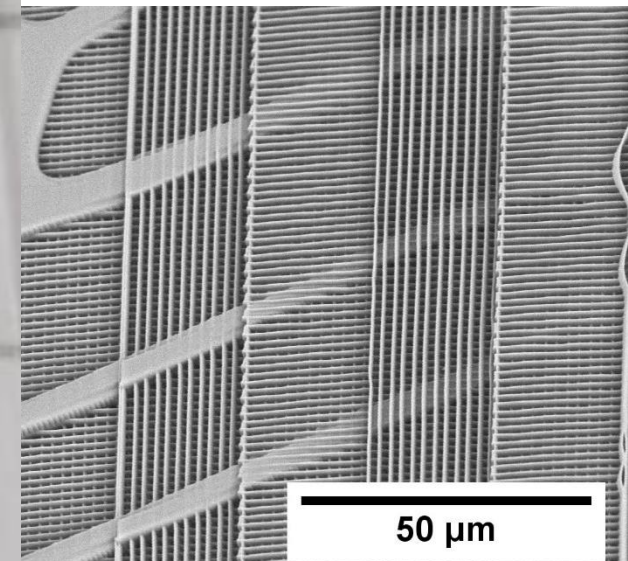
Meso-butterfly

Suspended antennas



Microlenses

Embedded nanolattice



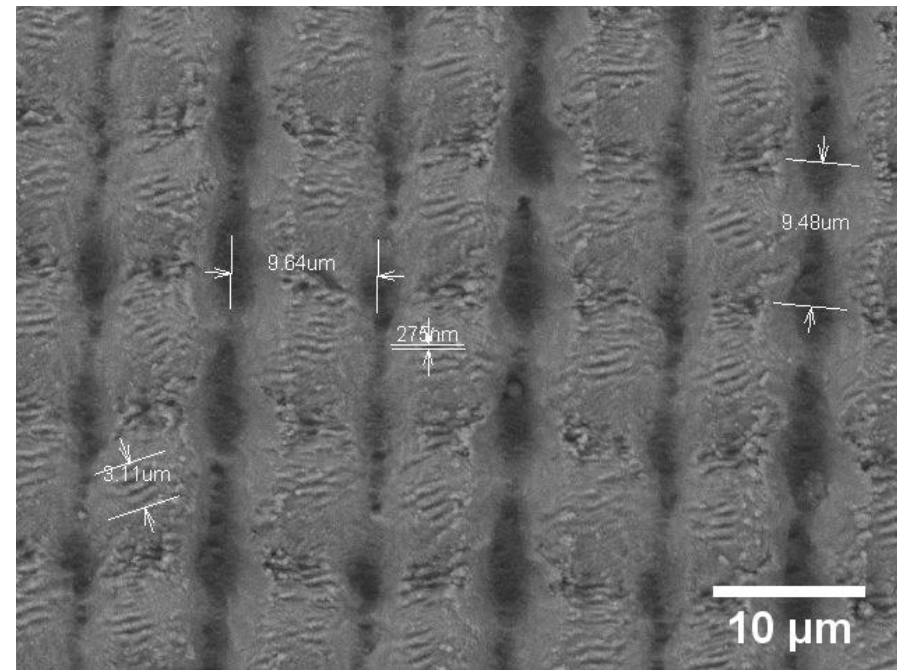
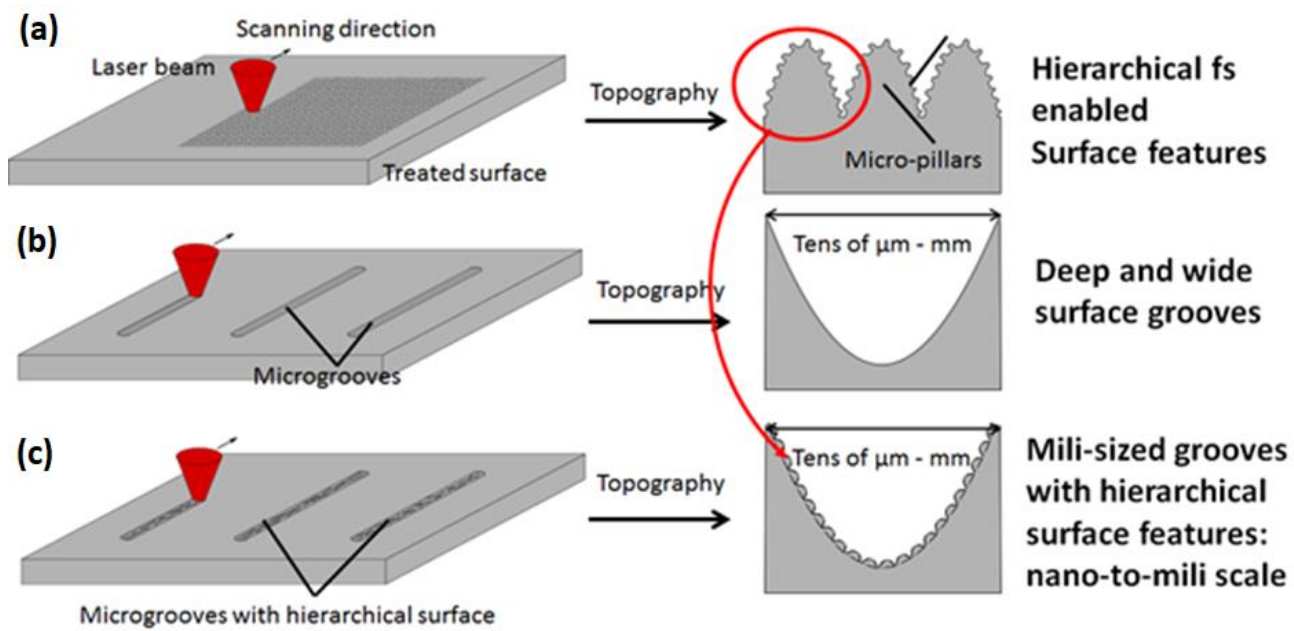
Functional material: SZ2080 + Rhodamine

Stitch-free

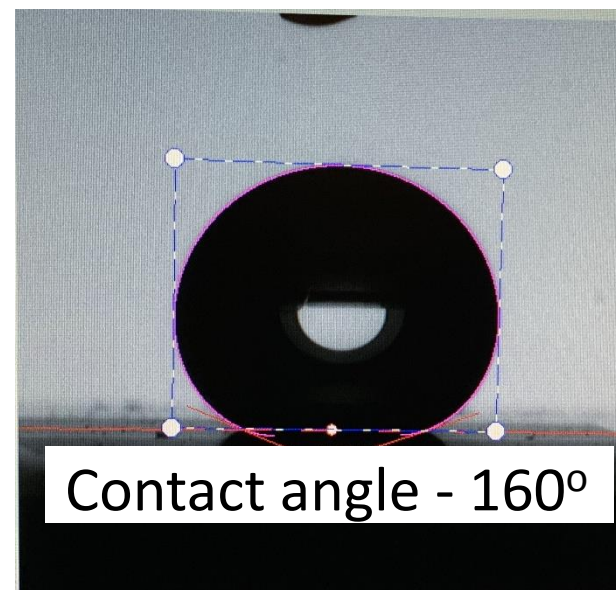
Printing time – 1:30 h

Line width ~ 650 nm₁₁

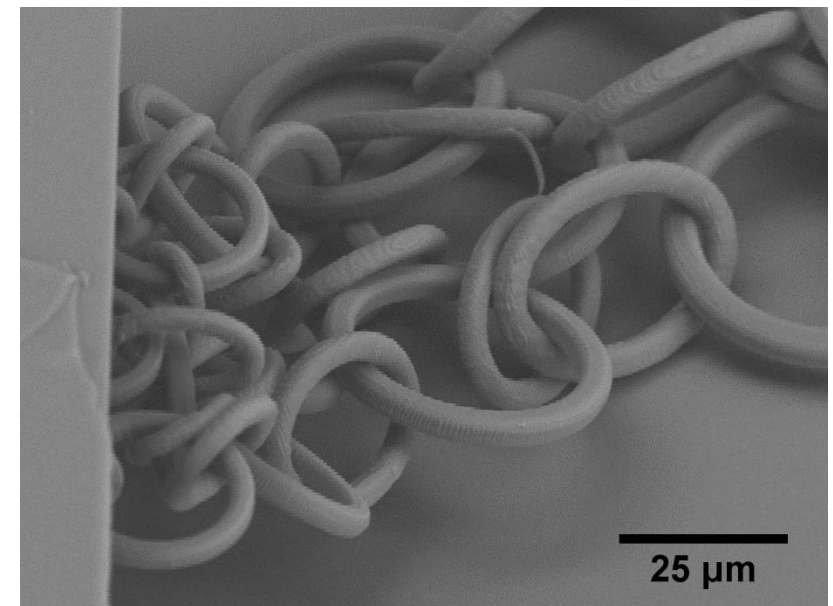
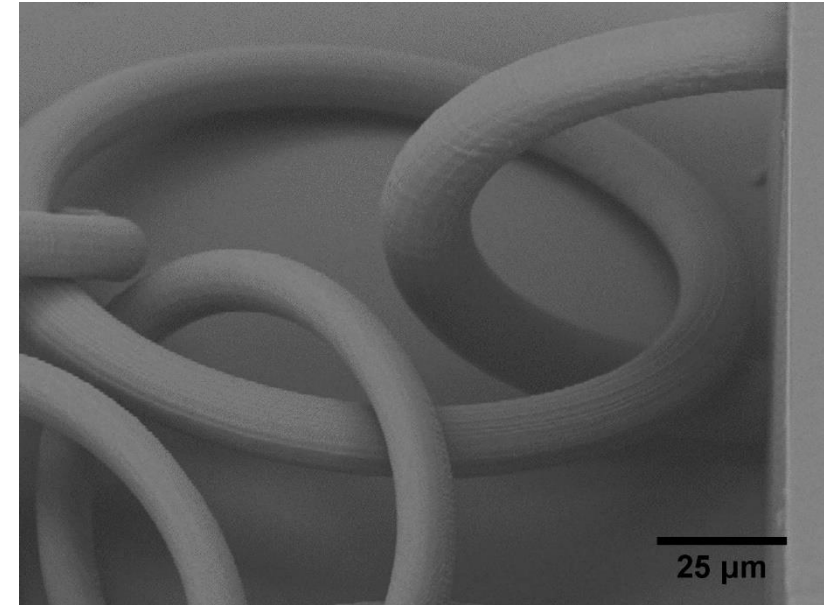
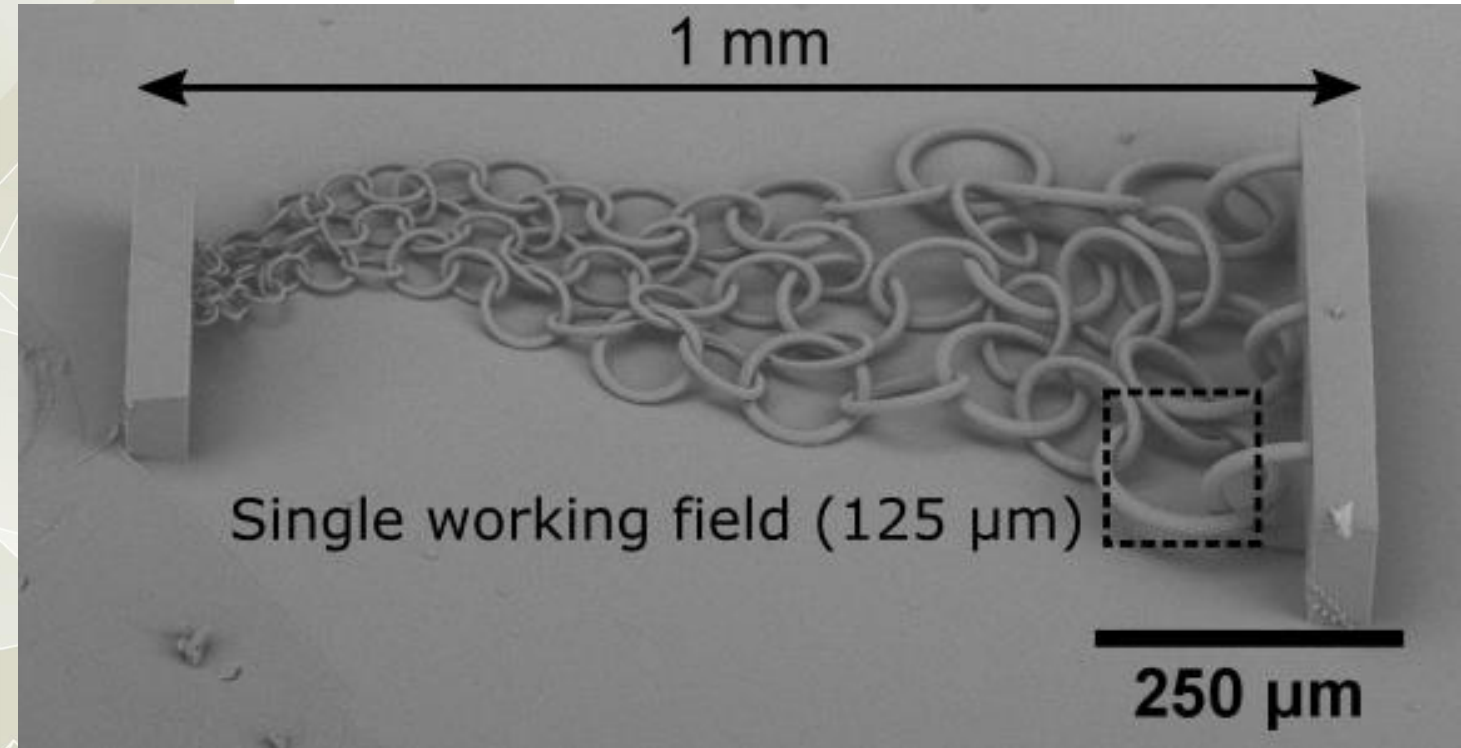
Femtosecond laser surface structuring



Application of fs laser allows to achieve **hierarchical nanogrooves** (a), **micro-features** (b) and **combine them together** (c). This enables the control of surface **wetting, photonic and related properties**. Can be used to create hydrophobic or hydrophilic surface.

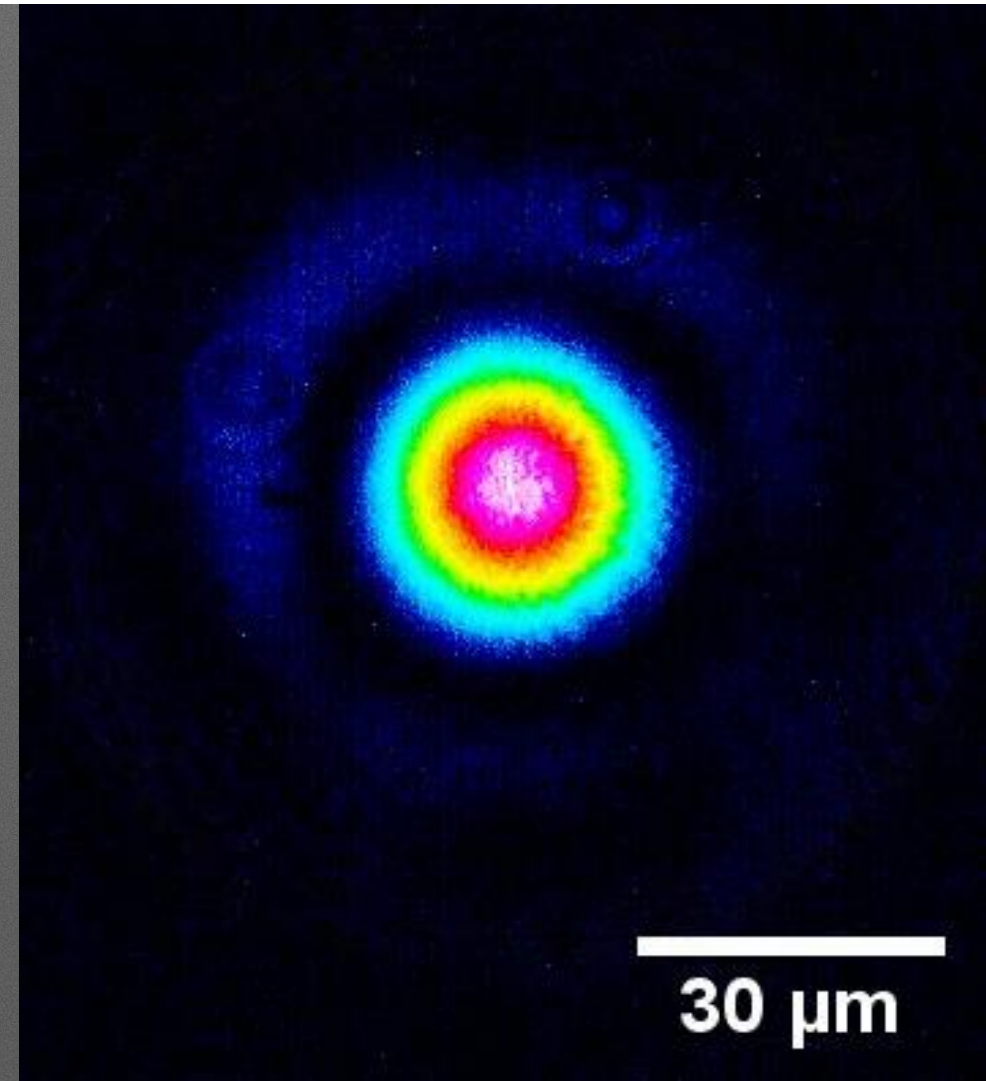
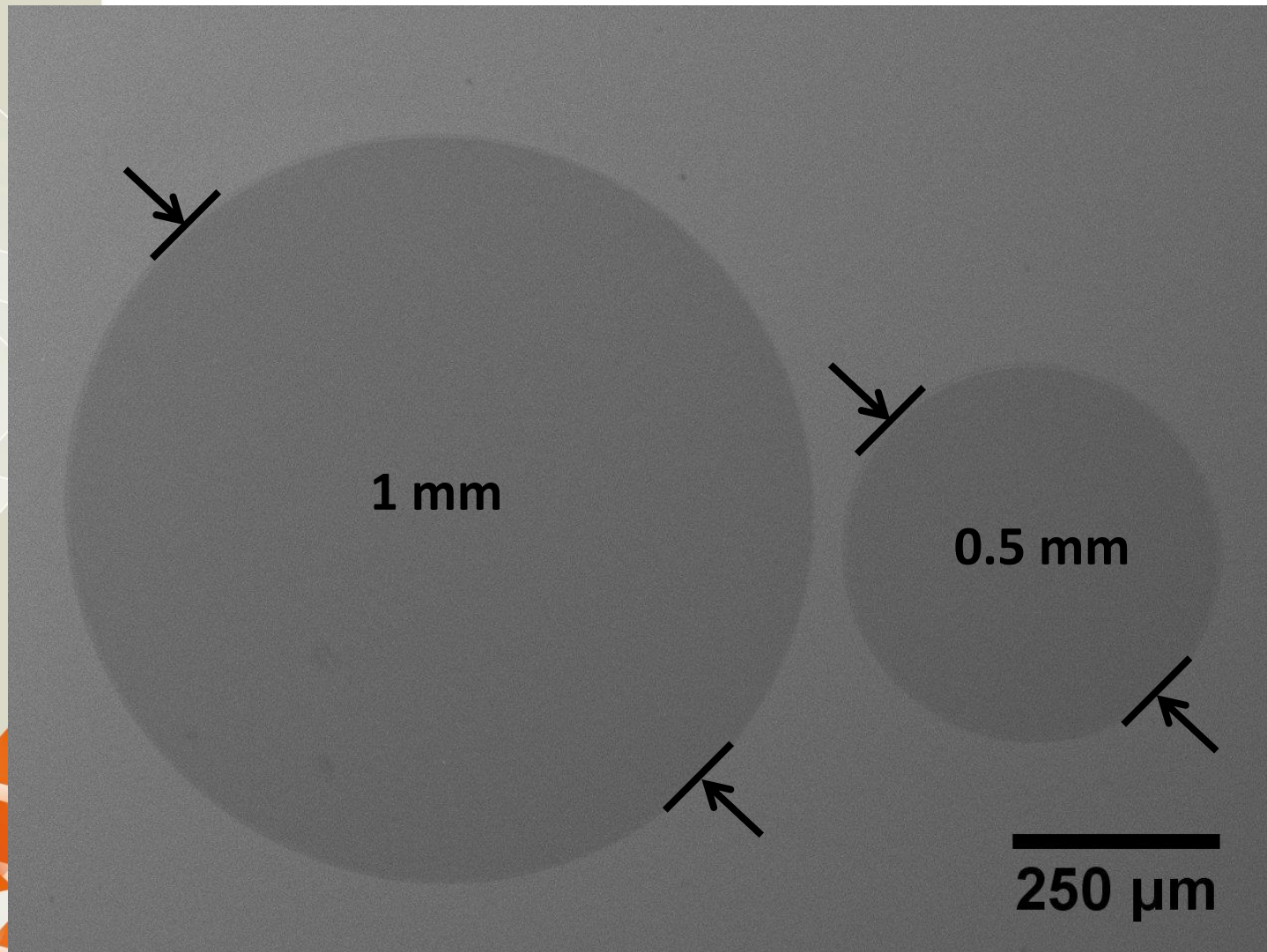


Gradient chainmail (flexible scaffold)



Chain and supports are printed with varying (**dynamic**) **slicing and hatching** steps for increased printing **efficiency**.

Applications: Micro-optics



Stitch-free micro-optics in the range of millimeters.

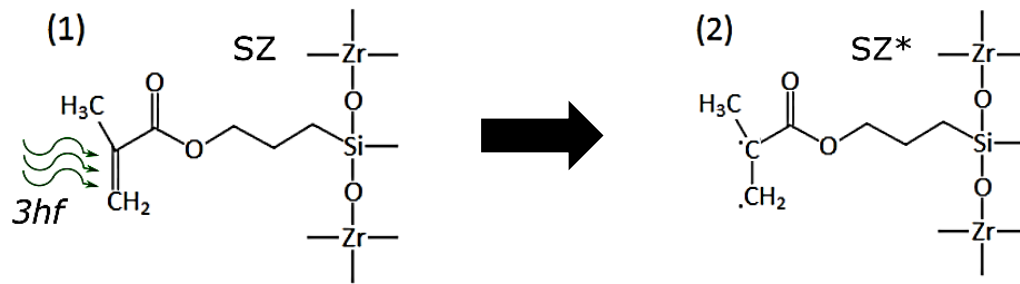
Focusing (0.5 mm lens)

Thermal post-processing of SZ2080

Material: hybrid polymer SZ2080 with wt% ratio 2:8 of inorganic (Zr) – organic (Si containing acrylates).

Laser writing

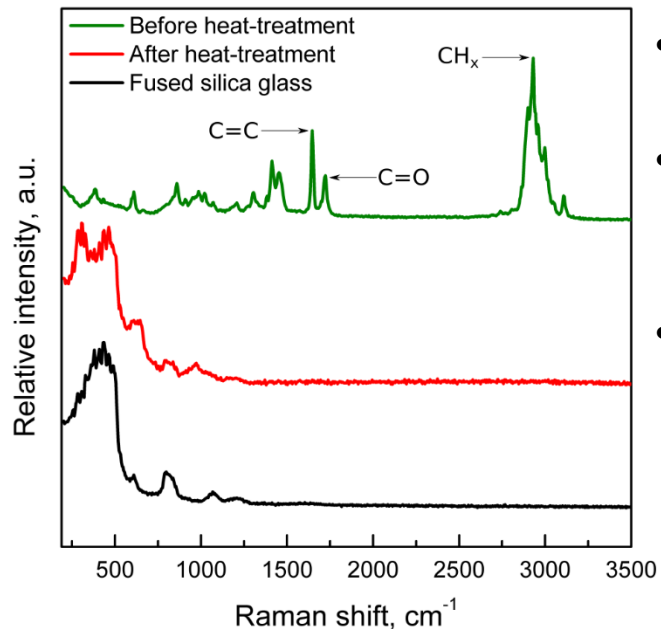
Heat Treatment



Jonušauskas et al., Materials **10**(1), 12 (2017)

Atmospheres: Air, O₂, Ar (inert)
 Tested temperatures: 200-1500 °C
 Pre-treatment with H₂SO₄ + H₂O₂.

Micro-Raman spectra



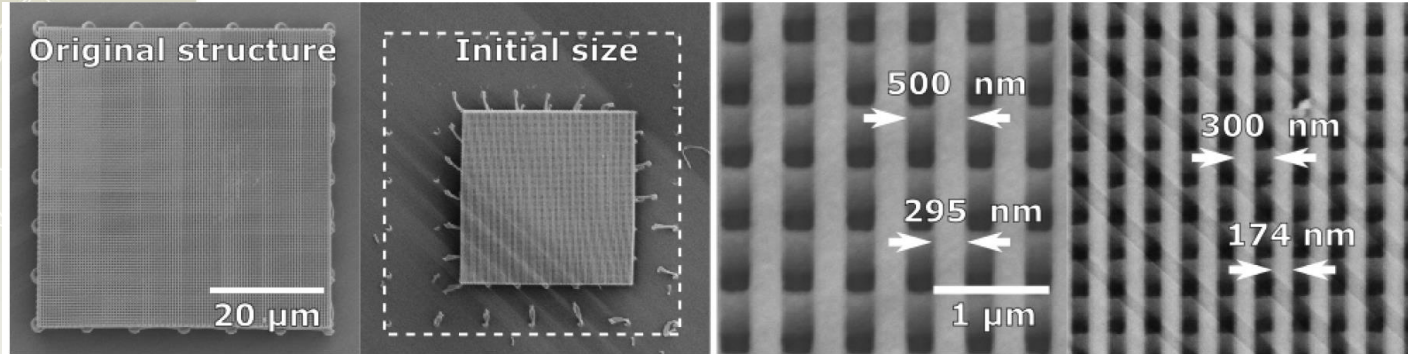
- Structures treated in 1000 °C in Air
- Initial vibrations of C=C; C=O; CH₂; CH₃ evident
- **After treatment organic vibrations non-present!**

Result: Cristobalite

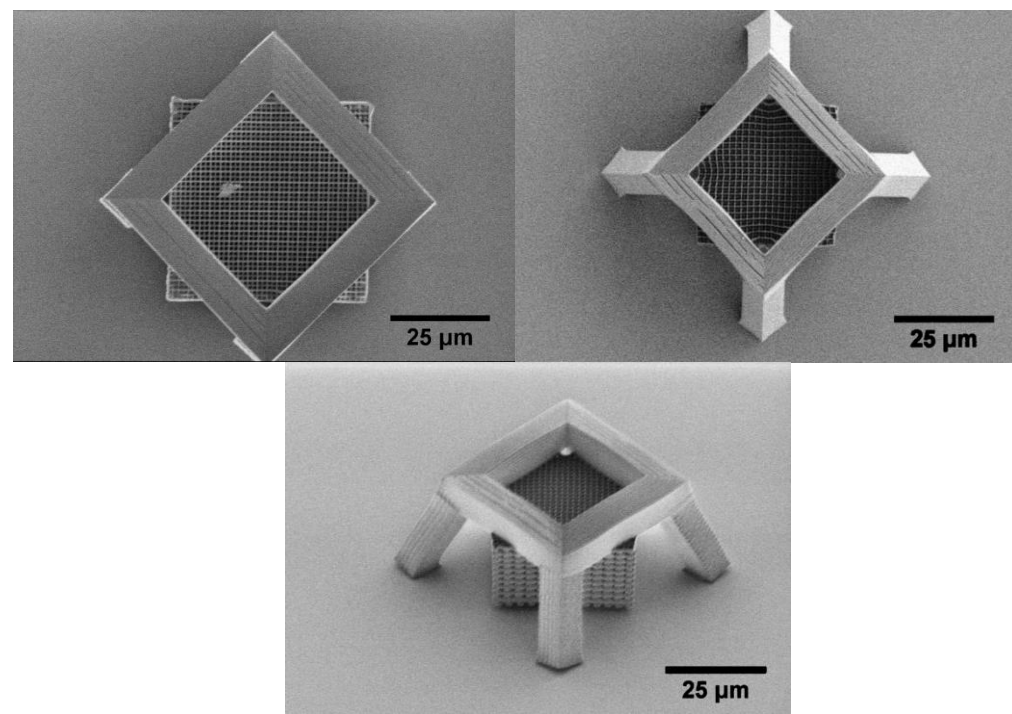


Downscaling bulks and lattices

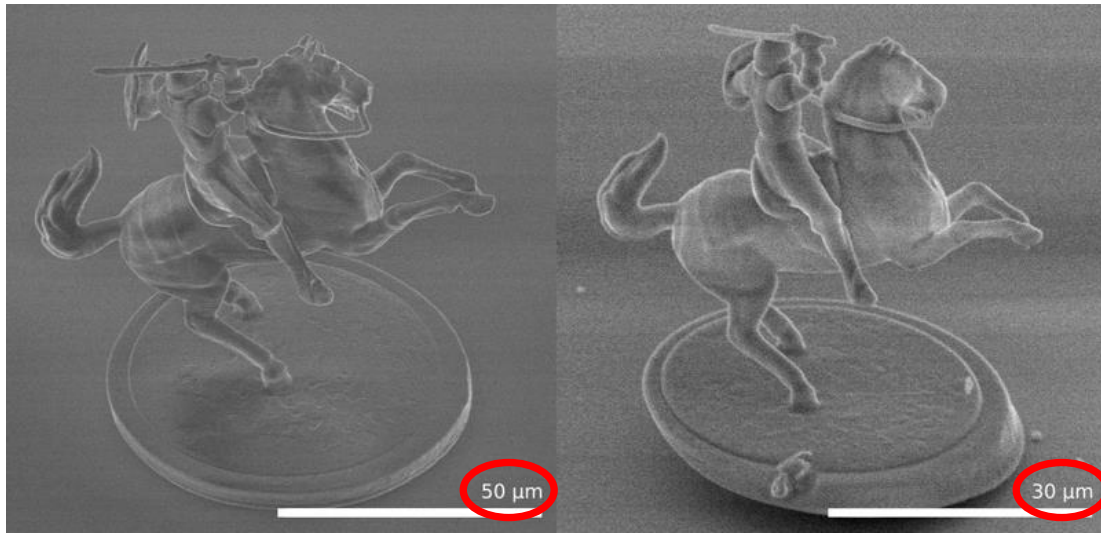
Nano-lattice



Nano-lattice + bulk



Complex 3D bulk



Uniform, consistent and well predictable feature down-sizing to **60%** of initial size!



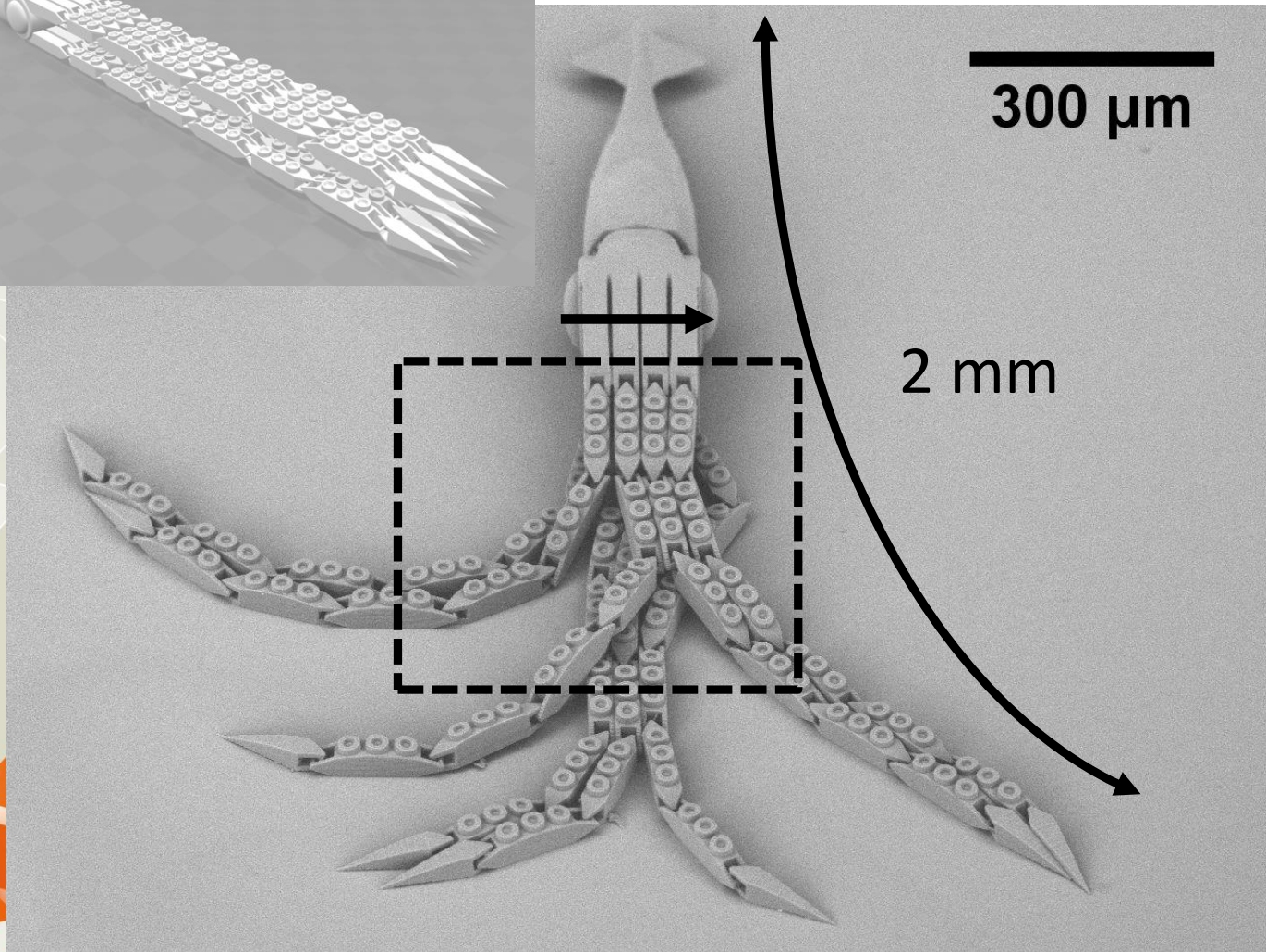
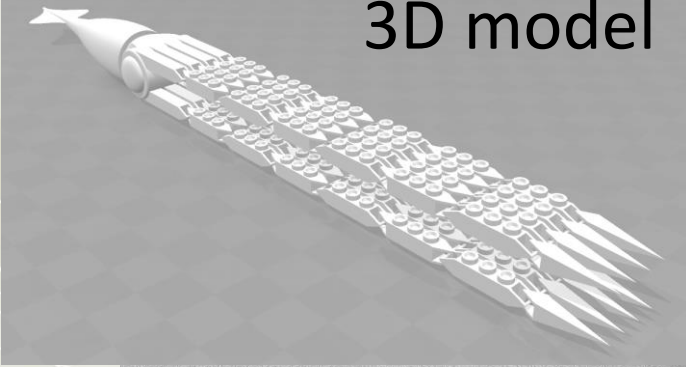
50 μm



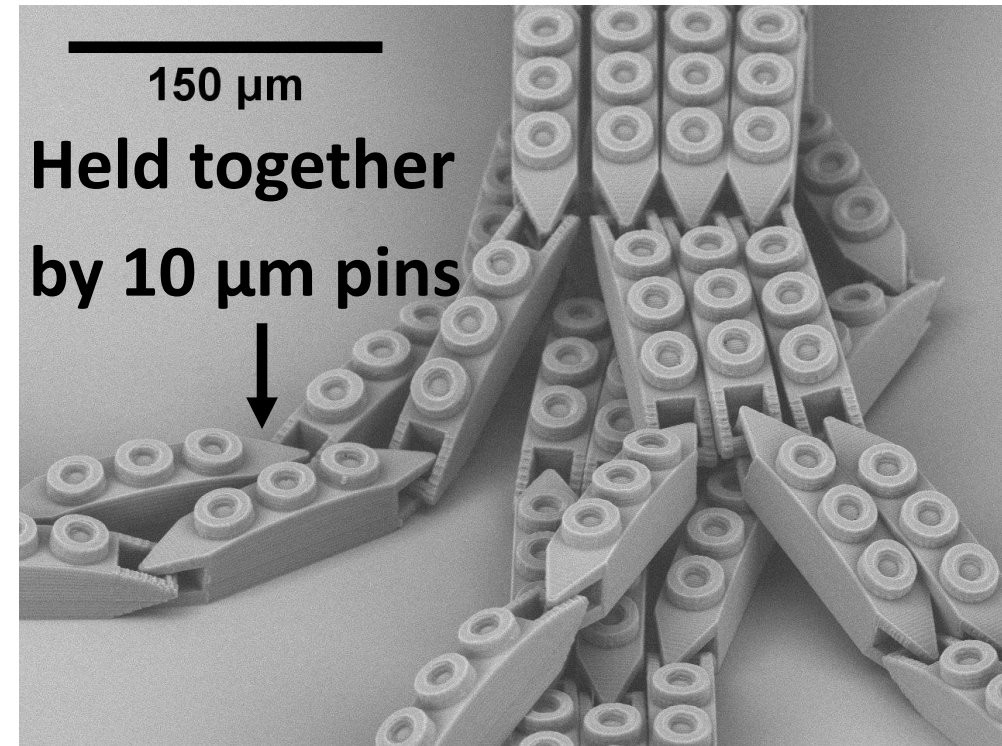
PHOTOJA ▶ NETOLI PAGĖGIŲ ANT APSEMTO KELIO ĮLŪŽUS MIKROAUT

Movable squid

3D model



Gecko-like suction cups



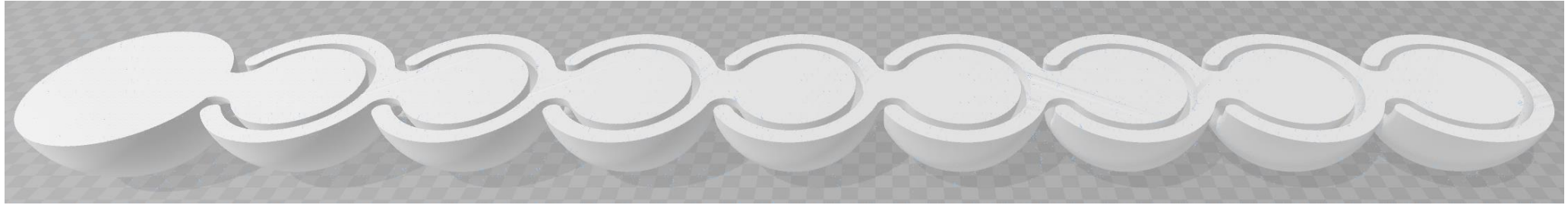
- Polymer is **hard gel** during fabrication – **no supports needed**;
- **Single printing step.**

Movement of the squid

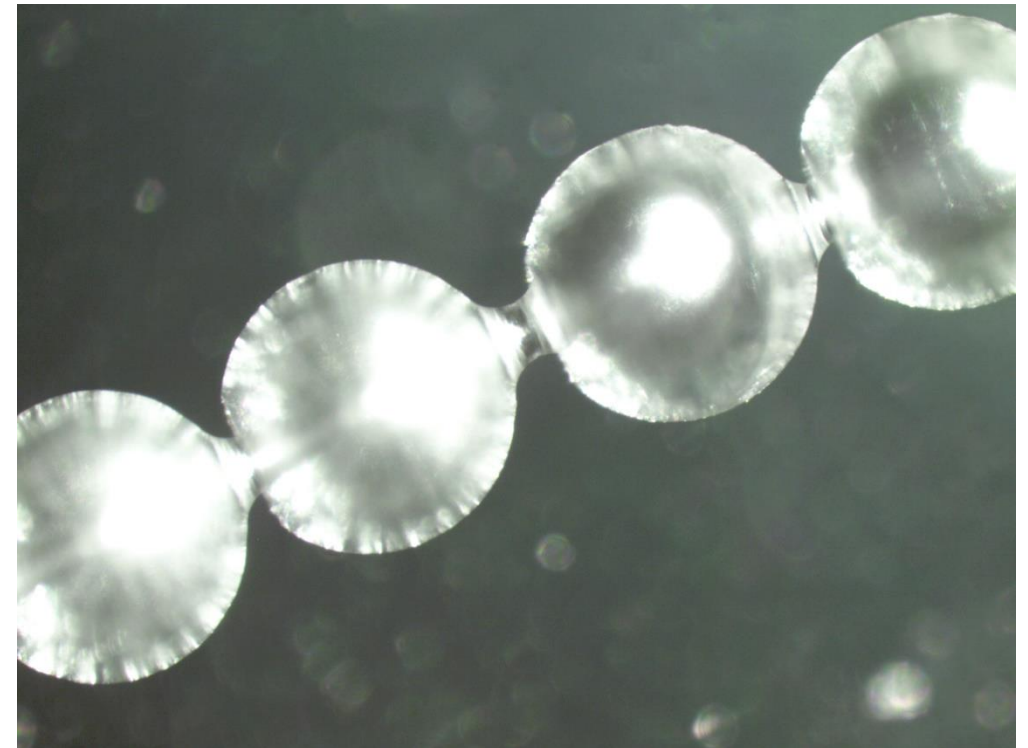
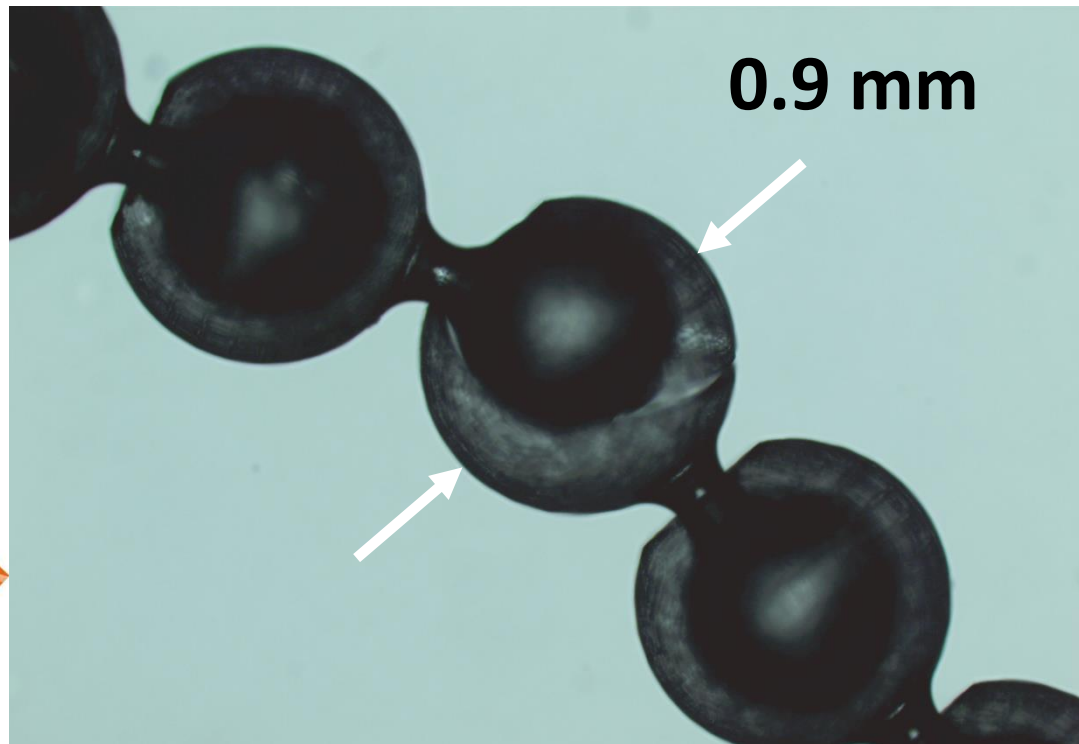


- **Sample is in liquid;**
- **Probe** is moving on the top of **meniscus;**
- **Capillary force** moves the squid;
- **Fluent and continuous movement** is observed;
- **No damage** to the structure.

Movable glass structures

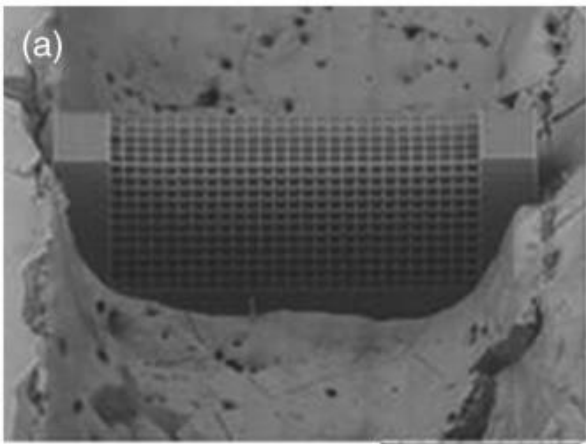


- **3D structurability** enables intertwined **movable glass** structures;
- **Bending** and **rotation** of structure is possible.

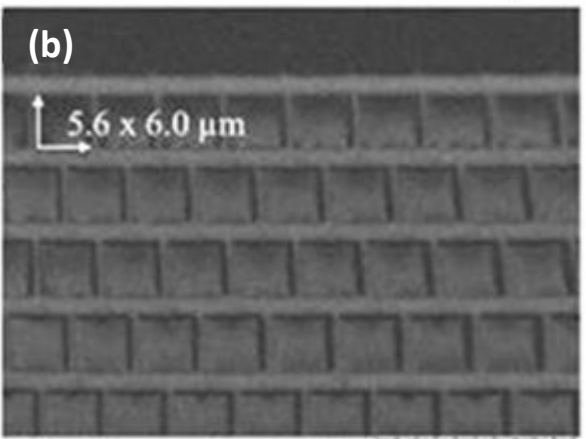


Hybrid fabrication in action: lab-on-chip

Jonušauskas et al., Opt. Eng. **56**(9), 094108 (2017).



100 μm

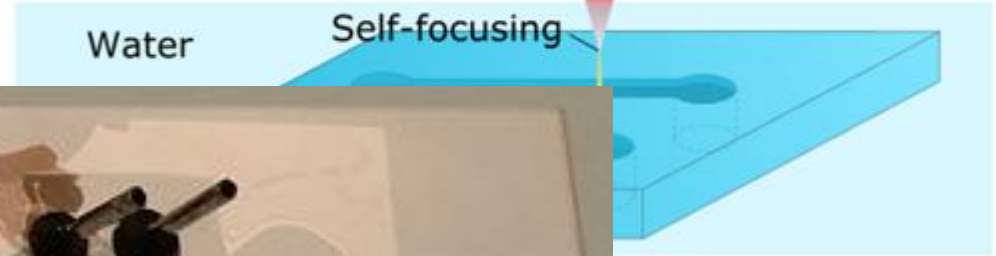


20 μm

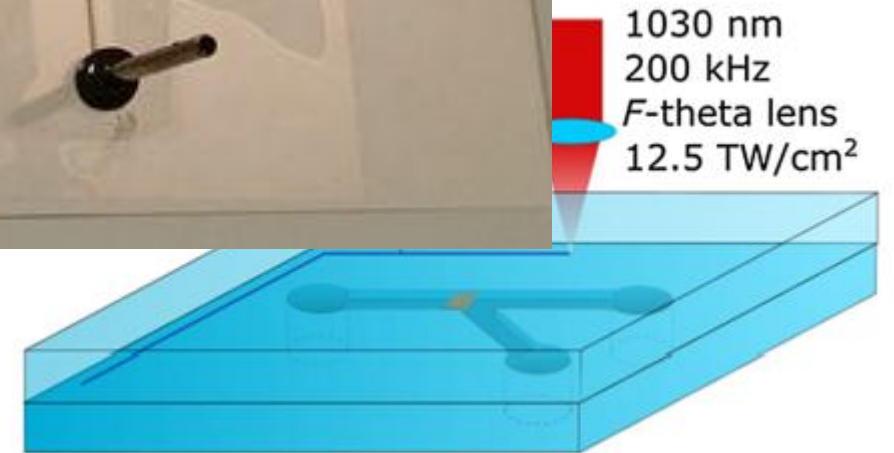
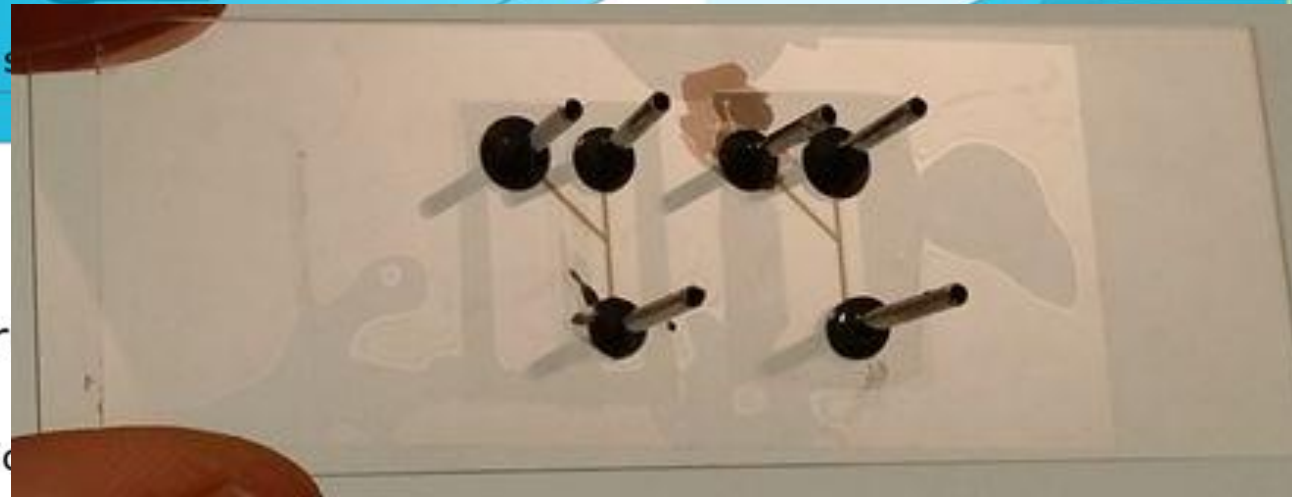
(a) Grooving
Laser beam
Channel
Glass substrate
1030 nm
25 kHz
F-theta lens
196 TW/cm²



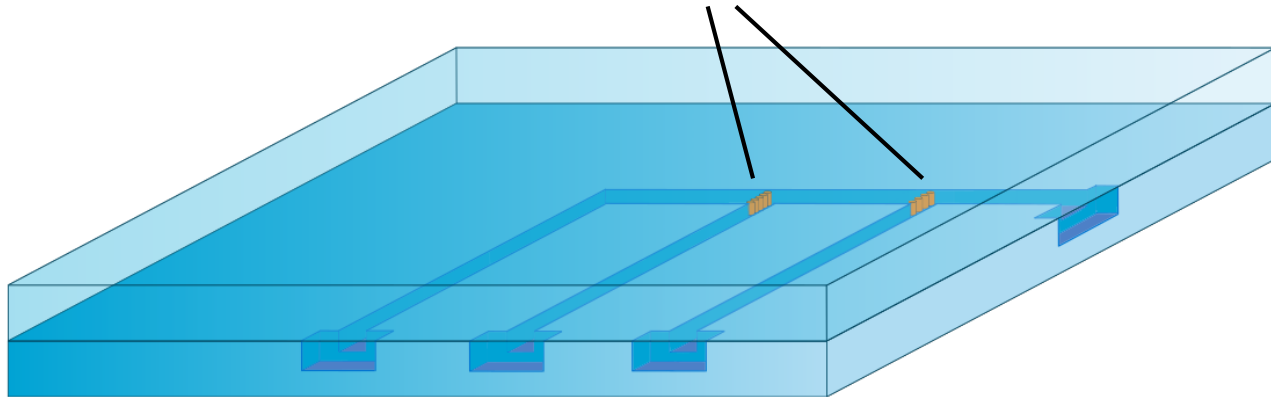
(b) Cutting
Water
Self-focusing
1030 nm
25 kHz
F-theta lens
196 TW/cm²



(c) 3-D structure
Microfluidic

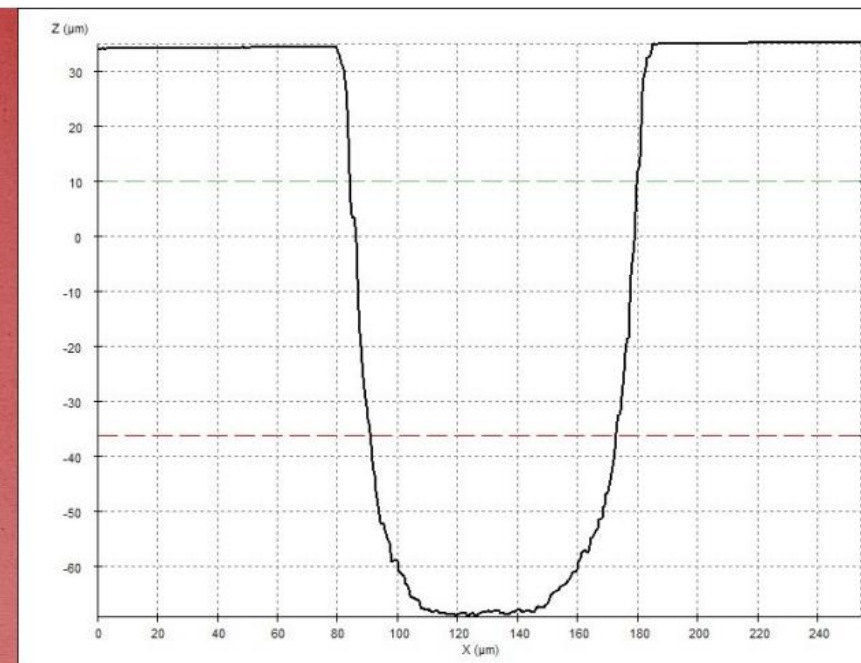
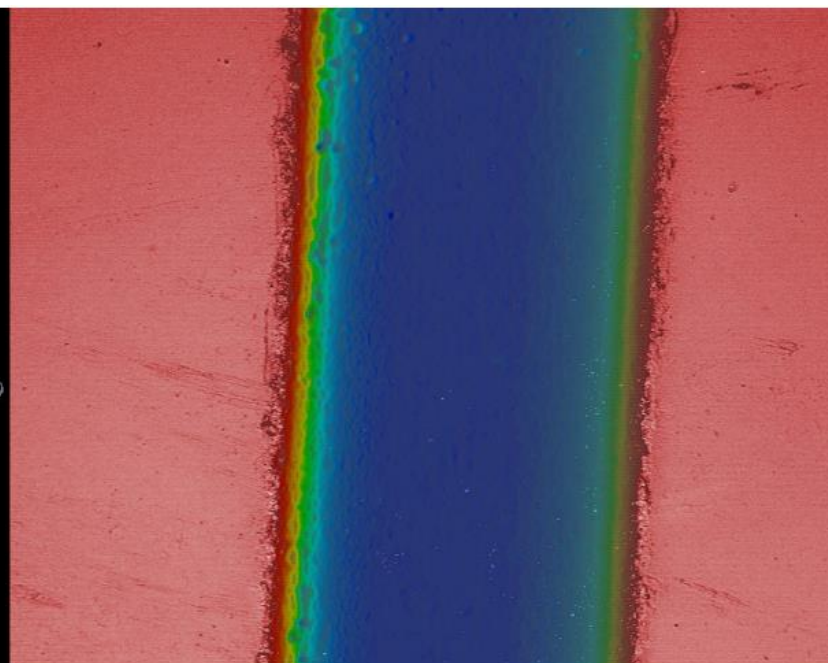
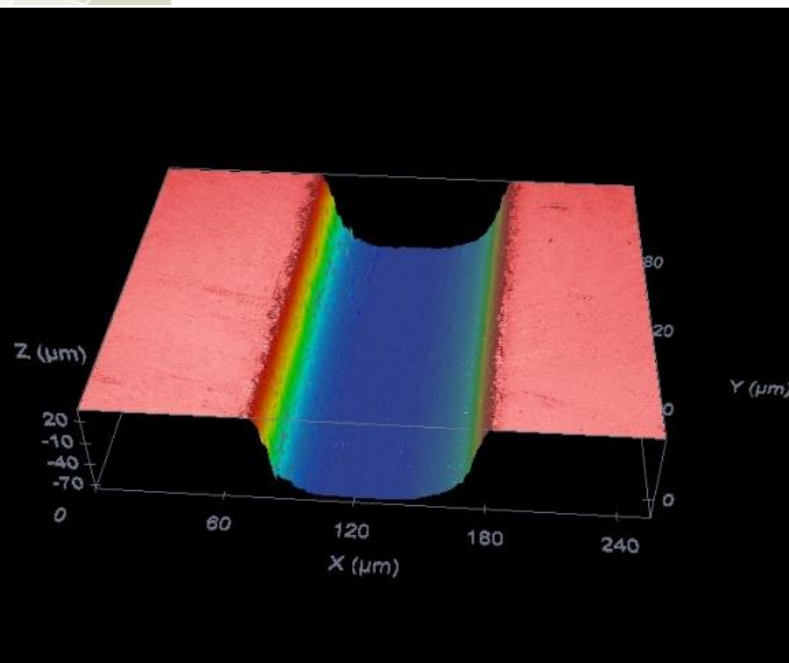


Filters (pore size – 0.5 μm and 1 μm)



- Chemically inert **glass channels**;
- Integrated ultra-high resolution multi-level **filters**;
- Towards **passive** macro-molecule **separation**.

Channel ablation results – **superb quality** and adequate profile



The way Femtika works



- Research of customer specific micro-structure fabrication method;
- Fabrication of microstructure prototype;
- Measurement and alignment with technical requirements;

- Development of micro-structure fabrication process;
- Development of mass production fabrication design;
- Development of needed machinery and automation;
- Batch production of product;

- Evaluation of site requirements and site preparation;
- Machinery manufacturing;
- Installation on site, if needed inside of existing production process;
- Training of users;



Laser-based Micro- and Nanoprocessing XIV, Session PTue

4 February • 6:00 - 8:00 PM

Titas Tickunas *et al*: Dynamic voxel size tuning for direct laser writing



Laser 3D Manufacturing VII, Session 3

4 February • 2:30 - 2:50 PM

Titas Tickunas *et al*: Towards the improvement of axial resolution:
4Pi multiphoton polymerization

Laser-based Micro- and Nanoprocessing XIV, Session 6

5 February • 9:50 - 10:10 AM

Gedvinas Nemickas: Surface structuring by high power
femtosecond laser for industrial applications



Laser 3D Manufacturing VII, Session PTue

4 February • 6:00 - 8:00 PM

Linas Jonusauskas *et al*: Meso-optical elements printed via 3D laser
lithography



Laser 3D Manufacturing VII, Session 9

6 February • 8:50 - 9:20 AM

Linas Jonusauskas *et al*: Hybrid additive-subtractive femtosecond
laser 3D fabrication of medical microdevices



Questions?

Ačiū!

Thank you!

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