Micro- and nano-formation of complex 3D glass-ceramic structures

Vilnius University

SUMMARY

Technology allows manufacturing complex 3D glass-ceramic micro- and nanostructures, by combining ultrafast 3D laser nanolithography with calcination. Inorganic glass or crystalline nanostructures are resilient in harsh physical and chemical environments, while maintaining high optical quality.

BACKGROUND

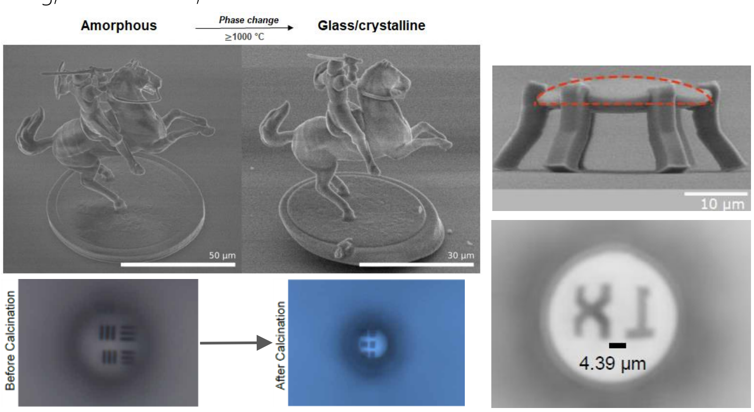
3D printing is a simple, low-cost and flexible technique. Combining additive manufacturing, done by ultrafast lasers, with heat treatment helps down-scaling dimensions of nanostructures, while preserving their initial geometry. To improve physical characteristics, metal nanoparticles may be added, however that will roughen the structures. That limits their application, where pure inorganic materials, optical quality and structural uniformity are required.

TECHNOLOGY

The present technology is based on combining Direct Laser Writing (DLW) 3D lithography technique with calcination. DLW is used to produce initial 3D structures at high precision and resolution (hundreds of nm). Post-fabrication heating at high temperature makes organic part decompose, which results in glass or polycrystalline ceramic hybrid material. During the heating process, 3D nanostructures permanently and homogeneously scale down to 60 % of their original size, while maintaining their initial geometry, regardless of their shape [1]. The highest achieved resolution of a crystalline object is ~60 nm [2].

This technology is suitable for manufacturing micro-optic elements. E.g., we have produced micro-lenses of 28.5 µm, having 37.7 µm focal distance and resolving power of 4.39 µm [3]. Such lenses could be applied in nanophotonics, open space and remote sensing, where resilience to high intensity radiation, temperature or pressure variations, is needed.

The final structures are resilient in harsh physical and chemical environments and high temperatures. Such advantages enable production of highly resistant and durable functional micromechanical 3D structures, to be used in space, sensing, biomedicine, etc.



TECHNOLOGY READINESS LEVEL

1 2 3 **4** 5 6 7 8 9 Validated in lab

INTELLECTUAL PROPERTY

Know-how developed in cooperation between Vilnius University and Femtika.

PUBLICATIONS

[1] Additive-manufacturing of 3D glass-ceramics down to nanoscale resolution

[2] Laser additive manufacturing of Si/ZrO2 tunable crystalline phase 3D nanostructures

[3] Laser 3D printing of inorganic free-form micro-optics

BENEFITS

- True-3D ceramic or glass nano-structures with a resolution of elements down to 60 nm.
- High resilience in harsh physical and chemical environments and high temperatures.
- No need to alter the proportions of the initial structure.
- 3D nanostructures are purely inorganic, of high optical quality and structural uniformity.
- The processed material is suitable for producing functional micro-optic elements on a µm scale.

APPLICATION

The present technology can be used in various applications:

- Tailored narrow-band IR emission sources;
- Optical elements for sensor applications in nuclear power plants;
- Biomedicine;
- Air and space engineering;
- Nanophotonics.

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Technical Information: Direct Laser Writing 3D Meso-Scale Lithography

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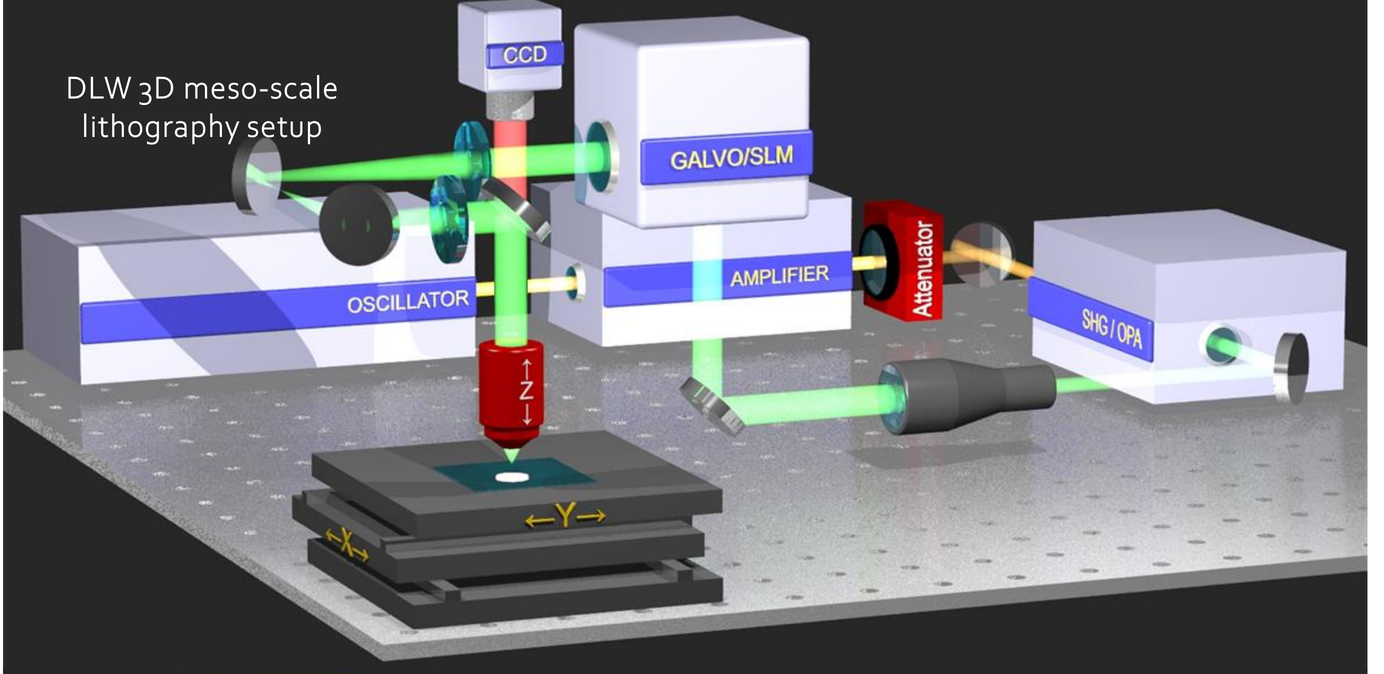
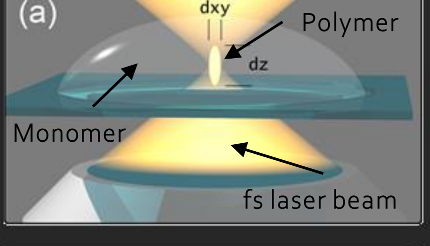
Direct Laser Writing (DLW, a.k.a. Two-Photon Polymerization, Multiphoton Processing) 3D lithography is a technique of precise additive manufacturing, accomplished by illuminating positive-tone or negative-tone photoresists via femtosecond pulsed light. This technique allows producing features on a scale of nanometres in a photosensitive material, without the need to use complex electron beam or UV optical systems or photomasks (see DLW 3D fabrication setup).

This technique relies on a multi-photon absorption process in a material. Typically its two-photon absorption when a simultaneous absorption of two-photons of the twice longer wavelength within the ultra-confined volume within a material restricted by the focus of a laser beam. It occurs once high intensities of light are reached (typically order of TW/cm^2). At the focal point of the laser beam a photochemical reaction, such as photopolymerization (photo-induced crosslinking), occurs (see a). In liquid resins, this process leads to liquid-to-solid transition (see b). By manipulating the position of the focal point in respect to volume of the modified material, e.g. by moving the stage (substrate) and/or scanning the beam, 3D structures are materialized. After the laser 3D structuring, the unexposed resin is dissolved in a developer (see c) and the fabricated structure is revealed (see d).

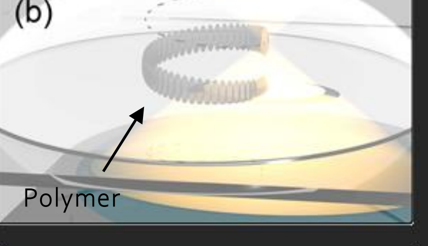
More details are available elsewhere: M. Malinauskas et al., Nanophotonics lithography: a versatile tool for manufacturing functional three-dimensional micro-/nano-objects, Lith. J. Phys. 52(4), 312 (2012)

DLW 3D meso-scale lithography setup



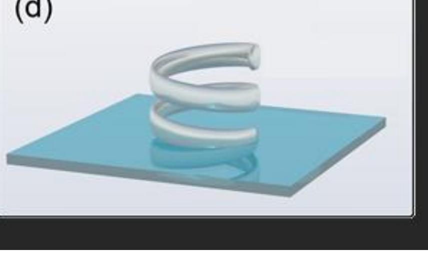


Photopoly-merization reaction is initiated in the focal point of the beam



Structure is directly written by moving sample in regard to the focal point

Organic developer washes unexposed material



3D free-standing structure is obtained on a glass substrate