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

SUMMARY

The present technology allows manufacturing complex 3D glass-ceramic micro- and nanostructures by combining ultrafast 3D laser nanolithography with calcination. As a result, inorganic glass or crystalline nanostructures become resilient in harsh physical and chemical environments and high temperatures.

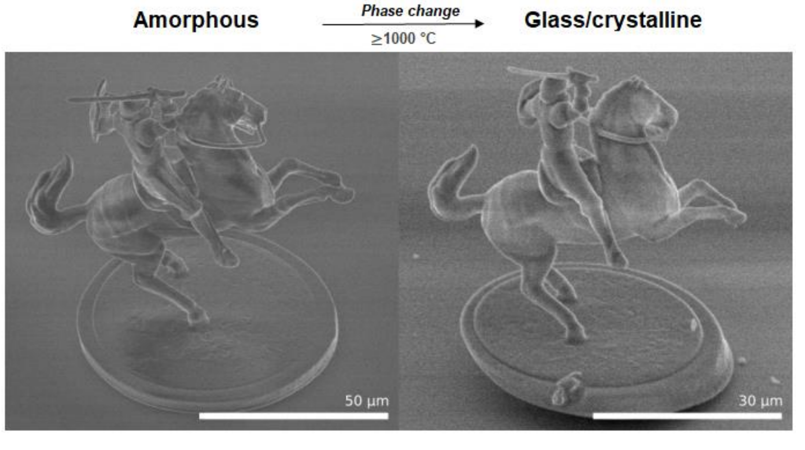
BACKGROUND

3D printing is a simple, low-cost and flexible additive manufacturing technique to create complex structures that cannot be cut, assembled or carved. This technique is especially useful in fabrication of micro- and nanostructures to be used in health area, nanoelectronics, nanophotonics, etc. Recently, combining additive manufacturing, done by ultrafast lasers, with heat treatment helped down-scaling the dimensions of nanostructures, while preserving their initial geometry. In order to improve physical characteristics of nanostructures, metal nanoparticles may be added, however that results in roughening of the structures. This limits their application for functional 3D nanostructures where pure inorganic materials and/or optical quality and structural uniformity of the patterns and work pieces are required.

TECHNOLOGY

The present technology is based on combining ultrafast 3D laser nanolithography with calcination. Direct Laser Writing 3D lithography technique allows the production of initial 3D structures with relatively small (hundreds-of-nm) feature sizes out of hybrid organic–inorganic material SZ2080. Post-fabrication heating at high temperatures facilitates the decomposition of the organic part, which results in glass or polycrystalline ceramic hybrid material. During the heating procedure, 3D nanostructures permanently and homogeneously scale down to 60 % of their original size, while maintaining their initial geometry, regardless of their shape [1].

Due to isotropic down-sizing of the initial objects, there is no need to alter the proportions of the initial material. The final structures become resilient in harsh physical and chemical environments and high temperatures. Such advantages allow production of temperature, radiation and chemical resistant, highly durable functional micromechanical 3D structures, to be used in space, sensor production, biomedicine, etc.



TECHNOLOGY READINESS LEVEL

TRL 4 – technology validated in the laboratory.

INTELLECTUAL PROPERTY

Invented in cooperation between Vilnius University and Femtika Ltd. by: D. Gailevičius, V. Padolskytė, L. Mikoliūnaitė, S. Šakirzanovas, S. Juodkazis, M. Malinauskas.

PUBLICATIONS

[1] D. Gailevičius, V. Padolskytė, L. Mikoliūnaitė, S. Šakirzanovas, S. Juodkazis, M. Malinauskas. Additive-manufacturing of 3D glass-ceramics down to nanoscale resolution. Nanoscale Horiz., 2019, 4, 647. https://doi.org/10.1039/c8nh00293b

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BENEFITS

- Possibility to get true-3D ceramic or glass structures with higher than tens-of-micrometers resolution.
- Resilience in harsh physical and chemical environments and high temperatures.
- Due to calcination, structures shrink to 60 % of their original size, while maintaining initial geometry, regardless of the complexity of the structure.
- No need to alter the proportions of the initial material.
- 3D nanostructures are purely inorganic, of high optical quality and structural uniformity.

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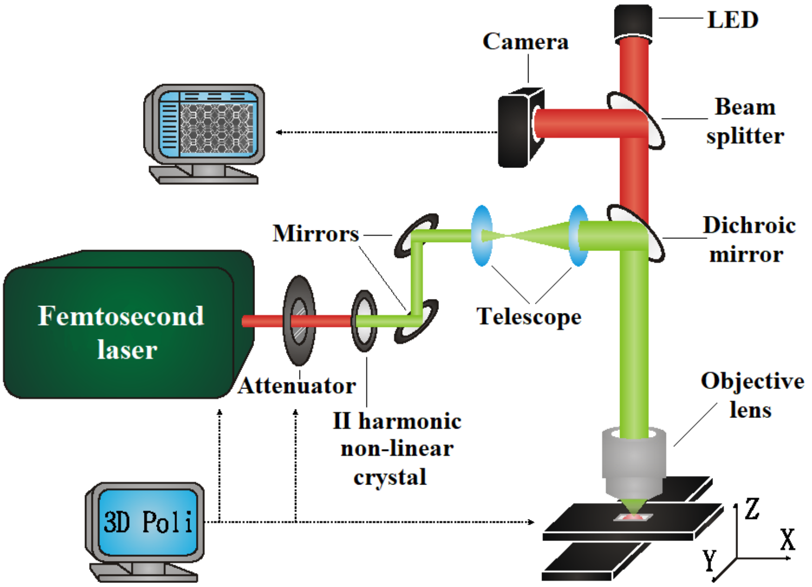
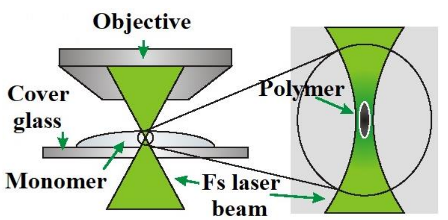
Technical information: Direct Laser Writing 3D Meso-Scale Lithography

DLW 3D MESO-SCALE LITHOGRAPHY SETUP

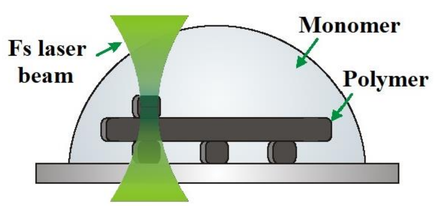


DLW 3D MESO-SCALE LITHOGRAPHY PROCESS

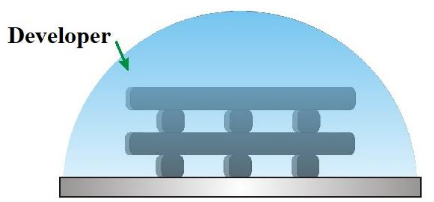
(I) photopolymerization reaction is initiated in the focal spot of the beam



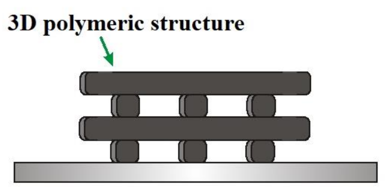
(II) polymeric structure is directly written by moving the sample in regard to the focal spot



(III) organic developer washes unexposed material



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



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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/cm2). At the focal point of the laser beam a photochemical reaction, such as photopolymerization (photo-induced crosslinking), occurs (see I). In liquid resins, this process leads to liquid-to-solid transition (see II). 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 III) and the fabricated structure is revealed (see IV).

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)