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3D selective laser glass etching for medical applications

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Abstract: Glass is one of the most common materials in medicine. It is used due to being biologically inert, having excellent optical transparency and the possibility to handle it easily. However, there are severe limitations in processing glass structures in 3D shape at µm scale. In this work, we present femtosecond laser-based selective glass etching as an attractive tool to produce medical glass structures. We discuss how it can be used to create various microfluidical and micromechanical systems. The challenges and capabilities related to the technology are highlighted, comparing it to other additive manufacturing techniques.

I. Introduction

Over the years, glass was proven to be material of choice in a multitude of rapidly developed science and engineering fields, such as microfluidics, micromechanics and micro-optics. The popularity of this glass, particularly fused silica, arises from its superb mechanical properties, being completely transparent for the visible and near infrared (IR) radiation and being chemically inert in organic solvents. Thus, there is a drive to produce various structures out of it. Especial interest is true 3D micro-structures embedded in glass. In essence, such structures combine overall size in practically usable mm-cm range with functionality enabled by the microfeatures. While various glass processing techniques exist, most of them are unable to produce 3D structures out of glass in such a scale or it is highly complicated. It is limiting the adoption of 3D glass structures in a lot of areas.

The most promising technology to produce 3D glass structures is selective laser etching (SLE) [1]. The technology is a two-step process, based on selectively modifying transparent medium via femtosecond (fs) laser radiation. The result is a II type modification formed in the volume of the material. Subsequently, the sample is submerged in the hydrofluoric acid or potassium hydroxide solvent that the modified regions are etched out from 10-1000 times faster than the unmodified medium. This allows true 3D subtractive glass manufacturing. Nevertheless, this process is not exploited widely so far. The problem lies in the complex nature of light-matter interaction and challenges in optimizing the technique for industrial 3D fabrication out of glass. Laser parameters, polarization, overlapping, translation velocity, etchant concentration and etching time are all important factors that cannot be disregarded in SLE [2,3]. Furthermore, selectivity dictates that in order to acquire complex shapes, the geometry of the structure should be altered to account for the dissolving of unmodified regions. Thus, overall, while the premise of SLE is simple, realization was proven to be rather complicated so far.

The aim of this work is to uncover ways to simplify the production methodology of SLE while still maintaining an acceptable quality of fabricated structures. The improvements to the technique include the adoption of circular polarization, non-tapered models and high-spacing hatching, which in turn both simplify and accelerate the processing. The methods are then employed to manufacture complex microfluidic systems and assembly-free micromechanical structures. These include various channels, deformable 3D objects, chainmail-like structures, flexible structures with ball joints, and freely rotatable gears (e.g. Geneva mechanism), to name a few. All of these structures are evaluated qualitatively and quantitatively, showing that simplified fabrication techniques do not compromise the quality or functionality of the structures. The acquired results are shown in the broader picture, relating it to previous SLE works, additive manufacturing and potential application areas.

II. Material and methods

The work was performed using “Laser Nanofactory” workstation (Femtika, Lithuania). This setup is based on amplified Yb:KGW laser source “Pharos” (Light Conversion, Lithuania) operating at 1030 nm fundamental wavelength, 200 fs pulse duration and 610 kHz pulse repetition rate. The laser light is then directed through optical chain to sharply focusing objective lens (NA=0.45). Sample positioning is realized using Aerotech stages (USA). A linear stage and galvo-scanner synchronization is implemented in the system, allowing rapid translation velocity (up to several cm/s) and stitch-free fabrication in the whole working area of linear stages (16x16x8 cm). The system is controlled by proprietary software “3DPoli” (Femtika, Lithuania). More information on the setup can be found elsewhere [4].

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III. Results and discussion

One of the primary uses of glass in medicine is various equipment used to store and / or measure biological samples. In the case of SLE, it can allow down-size such components to µm-level, thus enabling true lab-on-chip (LOC) devices. LOC have a lot of advantages over standard bio-measurement systems, as it allows to use substantially smaller samples and potentially provide testing results faster. Such devices can also be made extremely energy-efficient or even working in passive fashion. The advantage of using SLE to fabricate LOC is the possibility to use a very high resolution of the technique (down to few µm) and acquire very high well-defined micro channels (Fig. 1). What is more, the surface finish of such a structure can be very smooth, with roughness being less than 1 µm RMS, thus allowing true laminar flow and easy manipulation of the liquid. This makes SLE an ideal candidate for bio-inert LOC device fabrication.

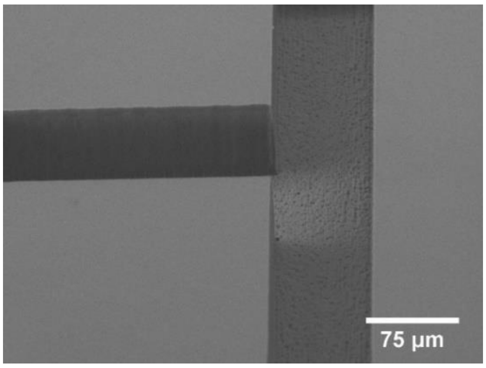

Figure 1: Example of SLE made microfluidical channel. Well-defined channel walls with minimal taper are evident. Surface rightness – less than 1 µm RMS.

One of the overlooked parts when it comes to medical microdevices are micromechanical elements. While mechanics are very common in macro scale it is tricky to realize those in micro scale. The reason lies in the production, manipulation and assembly of micro components of such mechanical systems. However, due to the peculiarities of SLE, it is possible to sculpt an entirely mechanical device out of glass without a need for assembly. Then, the whole volume of fused silica is exposed to laser light, which allows to inscribe already assembled parts. They are released during the wet etching part, which means that the whole mechanical system consisting of several elements can be produced assemble-free. To illustrate it, we produced a Geneva mechanism, which transforms continuous spinning into set movement (in our case 90 degrees turn) (Fig. 2). It is important to say, that while the whole structure is several mm in overall size, precise and smooth movement is possible due to µm-level precision of the SLE. Possibility to produce such structures opens entirely new possibilities in medical device manufacturing, as these could be employed as various micro-mixers, cell separators, perforators or sensors

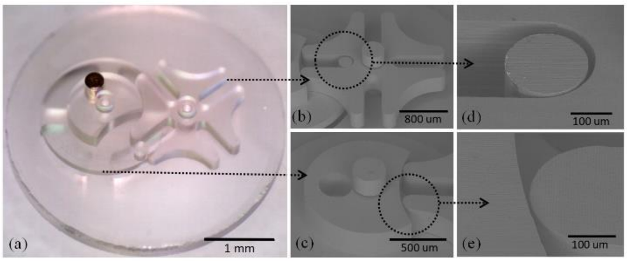

Figure 2: Images of free rotatable assemble-free Geneva mechanism made out of a single piece of fused silica by using SLE method. (a) – optical photo of the whole structure. (b) and (c) shows SEM micrographs of moving parts. (d) and (e) highlights extremely high precision of manufacturing – down to few µm.

IV. Conclusions

In this work, we show how SLE made glass micro-structures can be used in medicine. We highlighted that down-sizing of glass elements brings novel capabilities to the field such as LOC and micromechanics. In addition, SLE can provide a possibility to produce full, complex assembly free medical devices.

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AUTHOR'S STATEMENT

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

REFERENCES

[1] J. Gottmann, M. Hermans, N. Repiev, J. Ortmann, Selective laser-induced etching of 3D precision quartz glass components for microfluidic applications - up-scaling of complexity and speed, Micromachines, vol. 8, pp. 110, 2017.

[2] C. A. Ross, D. G. Maclachan, D. Choudrury, R. R. Thomson, Optimisation of ultrafast laser assisted etching in fused silica, Opt. Express, vol. 26, pp. 24343–24356, 2018.

[3] S. Butkus, M. Rickus, R. Sirutkaitis, D. Paipulas, V. Sirutkaitis, Fabrication of high aspect ratio channels in fused silica using femtosecond pulses and chemical etching at different conditions, J. Laser Micro. Nanoen., vol. 14, pp. 19–24, 2019.

[4] L. Jonušauskas, T. Baravykas, D. Andrijec, T. Gadišauskas, V. Purlys, Stitchless support-free 3D printing of free-form micromechanical structures with feature size on-demand, Sci. Rep., vol. 9, pp. 17533, 2019.