FABRICATION OF HIGH-VOLUME 3D 2-PHOTON POLYMERIZATION MICROSTRUCTURES

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INTRODUCTION

Multi-photon polymerization is a versatile tool within additive manufacturing technologies with rapidly growing applications including photonics [1], biofabrication and tissue engineering approaches [2]. 2-photon absorption, a non-linear optical process, occurs when two photons are absorped simultaneously by a molecule to exite it to an energy state higher than the energy of individual photons. In 2-photon polymerization (2PP) this phenomenon is employed to create arbitrary and complex 3-dimensional (3D) structures with feature resolutions down to a few hundred nanometres. A pulsed laser is tightly focused into photosensitive resin and moved in a 3D manner to locally crosslink polymers with high temporal and spatial control [3]. Typically, the overall size of the fabricated structures is no more than some 100 μm in each dimension. Despite the ongoing progress in the field of 2PP, fabricating larger structures while preserving sub-micrometre features remains challenging [4]. Due to this, most attempts to up-scale 2PP-structures are made in only one or two dimensions [5]. However, by adapting and optimizing the structuring technique and the material composition it is possible to produce constructs that are up-scaled in all three dimensions which results in not only large-scale but also high-volume 2PP-objects that show high-resolution features.

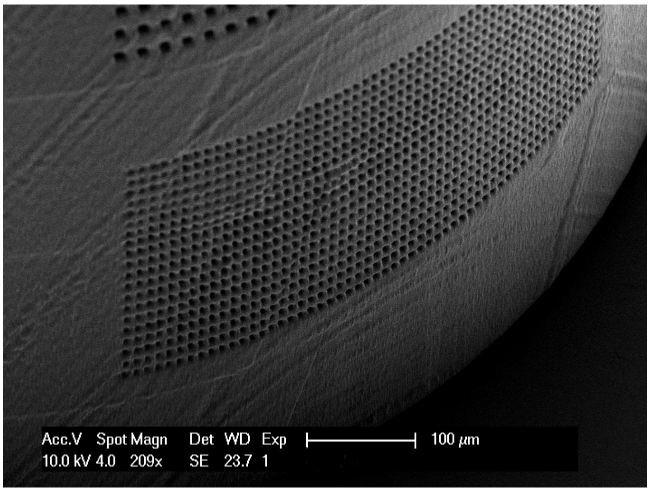

Figure 1: Close-up SEM-image of a high-volume structure with stitching areas and features with a size down to 5 μm.

EXPERIMENTS/FUNDAMENTAL OF THE PROBLEM/EXAMINATIONS

The main challenge when up-scaling in beam propagation direction are optical abberations that lead to an inhomogenious structuring process. This limits the focusing optics and impairs the printing resolution. To overcome this problem a sample mount with a wider objective working range (WOW-2PP) [6] was used. This technique enables to keep the focal spot distance in the material constant and reduces aberrations to a minimum. The objective used for the structuring process shows a limited field of view (FOV) that restricts the structuring area. To fabricate objects that exceed this FOV the printing area needs to be segmented. Therefore a high processing accuracy of the printing stage, suitable printing parameters and the spatial arrangement of the structured layers, called stitching, are fundamental (Fig.2). To create high-volume objects WOW-2PP was combined with an angular stitching arrangement. Since 2PP is a quite time consuming process it is crucial to fabricate larger structures with a high throughput system. Therefore a thorough understanding of the performance of the structuring materials is essential.

Further, large-scale structures show different mechanical behaviour than regular sized objects which is challenging the processed materials and may lead to undesirable effects such as tension and shrinkage. To overcome those problems two different categories of materials were tested and optimized.

RESULTS AND DISCUSSION

By combining a high writing speed of $1000\,\mathrm{mm\,s^{-1}}$ with a resin based on triacrylates, it was possible to fabricate stable high-volume 2PP-structures with dimensions up to $7\,\mathrm{mm} \times 7\,\mathrm{mm} \times 5\,\mathrm{mm}$ that showed features down to $5\,\mu$m.

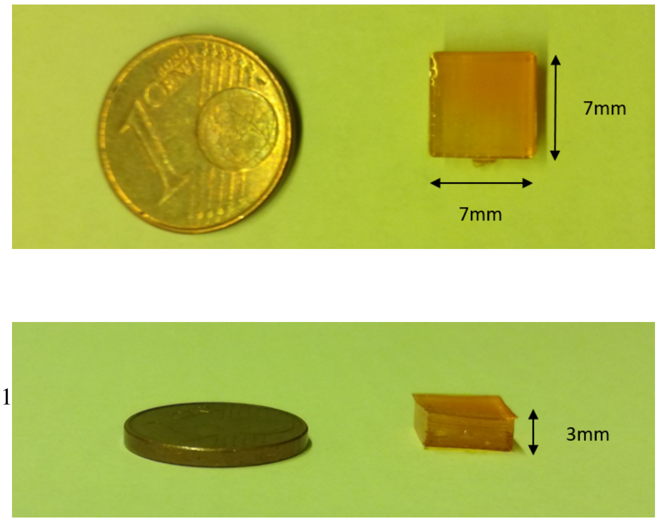

Figure 2: High-Volume 2PP-structure showing a size of $7\,\mathrm{mm} \times 7\,\mathrm{mm} \times 5\,\mathrm{mm}$.

CONCLUSION

Material composition and the fabrication technique are crucial to increase the size of 2PP-structures while remaining the resolution of the feature size. In order to fabricate even larger up-scaled structures the materials and printing set-up need to be adapted and improved further.

REFERENCES

[1] Deubel, M.; Wegener, M.; Linden, S.; von Freymann, G.; John, S.: *"3d-2d-3d photonic crystal heterostructures fabricated by direct laser writing"*. Optics Letters, 31 (6), p. 805–807, 2006.

[2] Ovsianikov, A. et al.:*"Engineering 3D cell-culture matrices: Mul- tiphoton processing technologies for biological and tissue engineering ap- plications"*. Expert Review of Medical Devices, 9 (6), p. 613-633, 2012.

[3] Baldacchini, T. :*"Three-Dimensional Microfabrication by Two- Photon Polymerization"*. In: Generating Micro- and Nanopatterns on Polymeric Materials. WILEY-VCH, p. 6107-140, 2011.

[4] Zhou, X.; Hou, Y.; and Lin, J.:*"A review on the processing accuracy of two-photon polymerization"*. AIP ADVANCES, 5(3), 2015.

[5] Malinauskas, M.et al.:*"Two-photon polymerization for fabrication of three-dimensional micro- and nanostructures over a large area"*. Proceedings of SPIE, 7204, 2009.

[6] Kotaro, O. et al.:*"High-aspect 3D two-photon polymerization structuring with widened objective working range (WOW-2PP)"*. Light: Science and Applications, 2, 2013.