High performance 3D-printed optical micro-systems

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INTRODUCTION

We present a review on our project PRINTOPTICS, looking back on 6 years of successful development of complex 3D-printed microoptical systems fabricated by femtosecond direct laser writing. Specific goal of the project was to realize the full value chain of optical design, simulation and manufacturing with suitable printing materials. Main benefit is a completely new generation of micro-optics, which combines free-form lenses in complex structures on a size of a few 10 to 1,000 µm. During the project we were on the one hand able to improve simulations methods and on the other hand to develop novel optical design concepts for 3D-printed imaging and illumination systems.

WAVE-OPTICAL SIMULATION

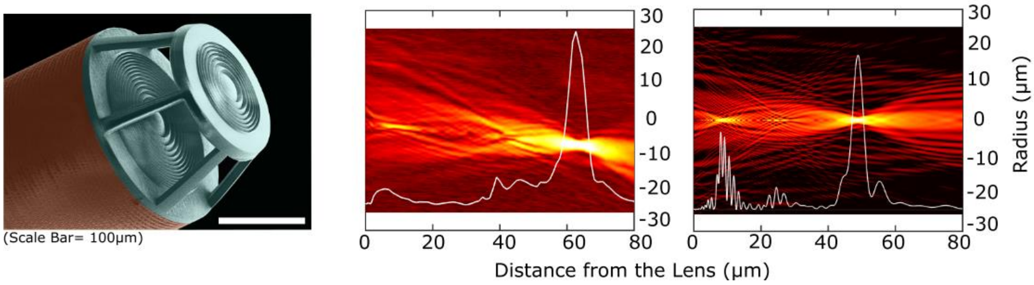

Fig. 1: 3D-printed diffractive focusing system for fiber-based trapping (left), measured beam profile (middle) and wave-optical simulation of the focal region (right) (Asadollahbaik, 2020).

For the wave-optical simulation of micro-printed systems, fast algorithms for light propagation were developed (Drozella, 2019). These are based on an implementation of the so-called wave propagation method (WPM). After successful testing, the algorithms were integrated into ITO's own open-source suite ITOM. The suitability of the wave-optical models was tested in comparison against the experimental measured properties of real printed optics (Fig. 1; Drozella, 2019; Thiele, 2019; Asadollahbaik, 2020).

OPTICAL DESIGN CONCEPTS & SYSTEMS

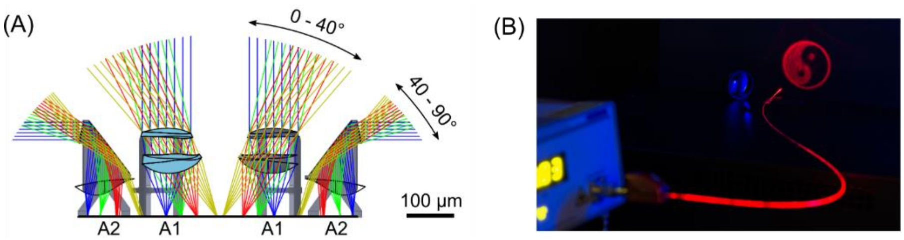

Fig. 2: (A) Flat wide-angle multi-aperture system that can be integrated directly onto an image sensor (Toulouse, 2022). (B) Fiber illumination system with 3D-printed optics for logo projection (Schmidt, 2020).

Regarding optical design concepts, a wide variety of imaging and illumination systems has been developed and optimized during the project under the constraints of 3D printing. For imaging applications wide-angle and tele systems, telecentric systems for endoscopic applications, hybrid refractive-diffractive, multi-aperture and off-axis systems have been designed, printed and tested. Fig. 2 (A) shows one example of an off-axis multi-channel imaging system, providing ultra-wide field of view (Toulouse, 2022).
Moreover, illumination optics, e.g. fiber-based optics, which enable extreme illumination angles, or optics which use total internal reflection or freeform surfaces to achieve complicated illumination distributions have been designed. Here, Fig. 2 (B) shows an example of a Ø 125 µm fiber-logo projector based on a hybrid refractive/diffractive freeform surface (Schmidt, 2020).

MANUFACTURING

For the manufacturing of such complex, small-scale, but high-performance optical systems, two aspects became very important: A method to generate absorbing apertures and stray-light shielding in the 3D-printed designs (Fig. 3 (A)), and accurate tools to measure the complex surface profiles in order to correct their shape (Fig. 3 (B)). For the creation of apertures, the ink-process which has already early been developed at ITO within the project (Toulouse, 2018) could be refined and was used in several demonstrators to increase contrast, or to provide apertures or entrance slits in imaging or metrology systems (Toulouse, 2021).

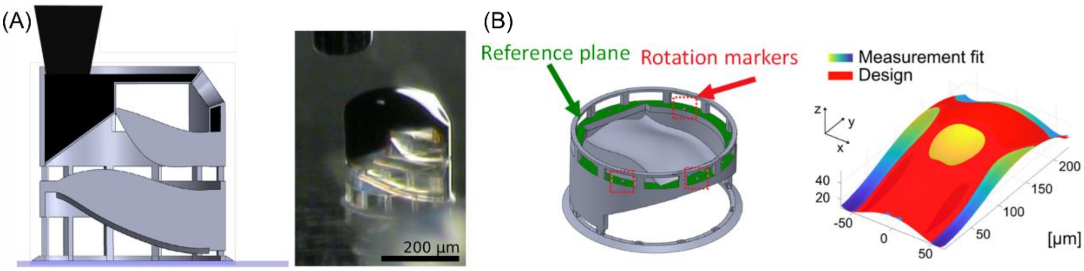

Fig. 3: (A) Ink-filled cavities in the design of an off-axis imaging system in order to define the stop. (B) Reference structures in the design of an off-axis imaging system for providing orientation of measurement data in the 3D-geometry (Toulouse, 2022).

CONCLUSION

In summary, the project PRINTOPTICS allowed us to continuously improve and fine-tune our methods in 3D-printing of microoptics. The goal of the project to realize the full value chain of optical design, simulation and manufacturing was reached.

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