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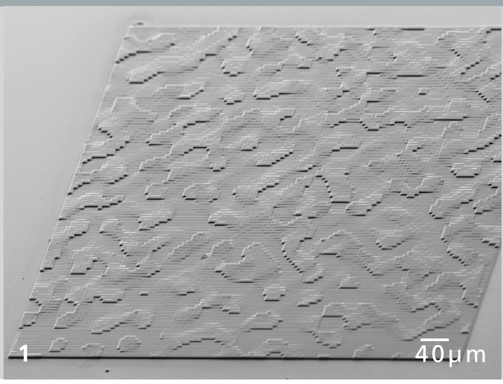

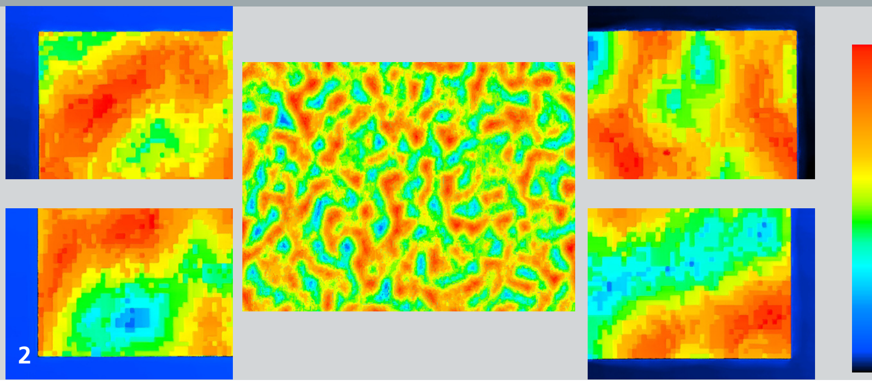

TWO-PHOTON POLYMERIZATION

FOR APPLICATIONS IN MICROOPTICS

1 *Multilevel Diffractive Optical Element (DOE) with 5 µm pixel size*

2 *Topographic characterization of a DOE using laser scanning microscopy (pixel size: 2 µm)*

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Many applications in everyday life as well as in laboratory environment are enabled by highly miniaturized and specially designed devices. Particularly the field of micro optics in e.g. micro-imaging, beam-shaping and integrated optics is a crucial factor for increased performance and further miniaturization of devices and setups. Aspheric and freeform surfaces might further advance the application of microoptics in optical systems.

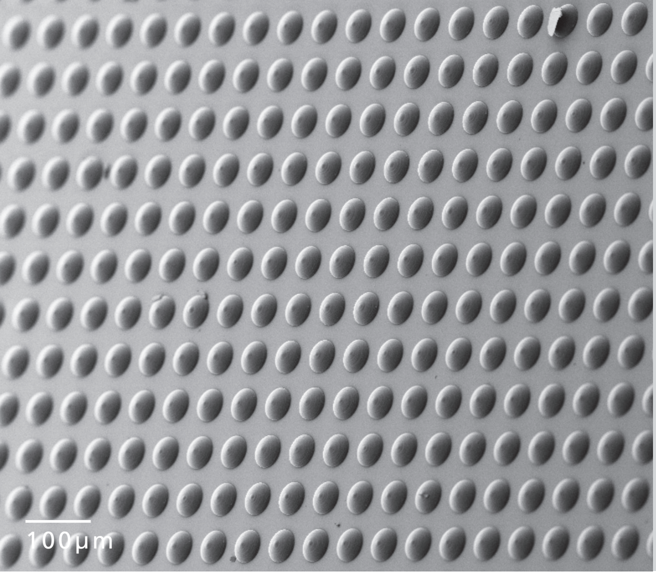
High quality optical components are often fabricated by glass although the glass processing might be very elaborative and cost-intensive. For micro optics and optics integrated on wafer-scale, polymeric materials are used frequently due to more simple processing. To combine the best of both worlds, inorganic-organic hybrid polymers can be used which have a glass-like organically modified backbone. The materials provide higher quality than conventional organic polymers and easy processing in the same time. Inorganic-organic hybrid polymers can be directly patterned by printing techniques, UV lithography, and UV embossing or Nanoimprint lithopgraphy.

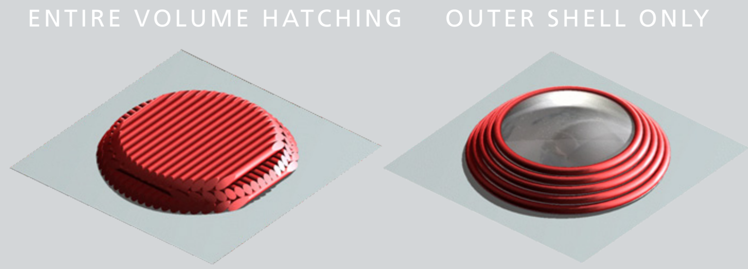
Processing of sophisticated micro-structures by Two-Photo Polymerisation

However, conventional technology platforms can only provide the fabrication of either spherical elements or 2.5-dimensional patterns.

Two-Photon Polymerization (2PP) on the other hand, is a versatile tool for the fabrication of nearly arbitrary 3D micro- and macrostructures. It uses tightly focused femtosecond laser pulses to confine the polymerization of a photopolymer to the focal volume. By scanning the focal volume and thus the tiny side of photochemically induced solidification in 3D space and by applying a subsequent solvent wash, true 3D structures can be generated.

This handout will demonstrate the benefits of using 2PP for the fabrication of diffractive as well as diffractive optics.





4 *Two approaches for lens fabrication: 1. 2PP fabrication of the entire volume. 2. Surface definition by 2PP (»shell«) and subsequent UV exposure of the liquid »core«.*

3 *SEM image of a freeform microlens array*

Diffractive Optics

Per design, diffractive optical elements (DOEs) diffract an incoming light intensity distribution into a desired intensity pattern. The necessary phase functions of the DOEs are computer-generated using iterative algorithms. In this iteration the simulated diffracted intensity of the nth phase function converges towards the desired intensity distribution. The performance of the DOE is indicated by the diffraction efficiency. This is dependent on the absolute number of phase levels. For instance, a binary DOE can only diffract approximately 60% of the light into the desired pattern, whereas a 16 level DOE is capable of 90% efficiency. This is exactly where 2PP is beneficial: In contrast to other technologies e.g. e-beam lithography, 2PP can generate continuous level DOEs without rendering the process more complicated (e.g. multiple exposure with different masks, multiple development etc.)

Fraunhofer ISC developed proprietary algorithms for transferring phase functions into machine code. By using these algorithms and optimized hatching strategies, it is possible to fabricate multilevel DOEs in very short times.

Typical specs

Pixel size:	*2 to 5 µm*
Pixel height:	*1.5 to 6 µm*
Number of pixels:	*1024 to 2048*
DOE size:	*2 x 2 mm²*
Fabrication time:*	*min - hrs*

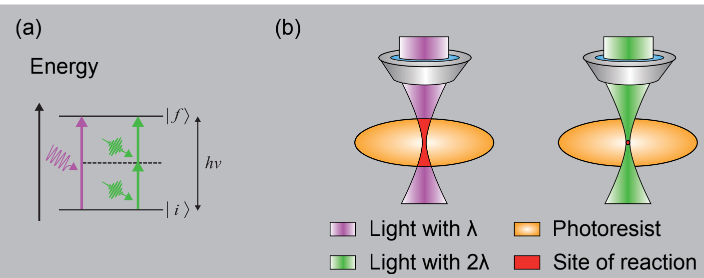
Microlenses

2PP can boost the performance of microlenses as the target surface function can be chosen almost arbitrarily. The generation of highly aspheric or entirely freeform surfaces is possible. Fraunhofer ISC developed particular algorithms and strategies to fabricate the elements with superior precision and on a short timescale. By adapting the employed material to the fabrication parameters, such as photon dose and hatching distance, optically smooth surfaces can be realized without any presence of individual hatching lines. The employed ORMOCER® materials exhibit low polymerization shrinkage. Additionally, this can be pre-compensated by software.

In addition, automatic substrate detection and large travel linear stages allow the fabrication of microlens array on large areas.

Typical specs

Lens diameter:	*50 to 250 µm*
Lens height:	*5 to 75 µm*
Surface accuracy:	*approx. λ/7*
Fabrication time:	*1 to 2 mins per lens*



(a) Quantummechanical scheme of 1PP (magenta) and 2PP (green) (b) Reaction volumes in 1PP vs. 2PP: Only 2PP enables the confinement of the photoreaction to the tiny focal volume.

We offer

- Feasibility studies for the generation of customerdesigned microlenses, DOEs, and other micro optical elements
- Optimization of throughput by tailored hatching strategies and new galvo-scanner (approx. 100x faster than stage-based fabrication) and semi-automated fabrication
- Replication of 2PP written elements for mid-volume production
- Fabrication in non-standard materials and material development towards new optical properties and functions.
- (Partial) compensation of aberration for highly reliable and precise surface generation
- Dip-In lithography in order to fabricate structures independently of the working distance of the focusing optics.

**Footnote: Fabrication time can be reduced drastically (factor of 100) when using galvoscanner technology which is available at Fraunhofer ISC.*