Q 77: Photonics – 3D Printing

Time: Friday 14:30–16:15 Location: P 2

Q 77.1 Fri 14:30 P 2

High-Fidelity Transfer of 3D-Printed Freeform Micro-Optics into Scalable Polymer Replication — •Leander Siegle[1], Stefan Wagner[2,3], Stephan Haeusler[3], Philipp Flad[1], Mario Hentschel[1], Thomas Günther[2], André Zimmermann[2,3], and Harald Giessen[1] — [1]4th Physics Institute, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Institute for Micro Integration (IFM), Allmandring 9B, 70569 Stuttgart, Germany — [3]Hahn-Schickard, Allmandring 9B, 70569 Stuttgart, Germany

We present a scalable process for fabricating aspherical and hybrid achromatic micro-lens arrays by combining two-photon polymerization grayscale lithography with electroplating and injection molding. Master structures containing 1632 lenses with 100-300 μm diameter and 100-1000 μm focal length were 3D-printed using a Nanoscribe Quantum X and replicated in cyclic olefin copolymer (TOPAS 5013L-10) using nickel molds. The replicas showed sub-micron deviations and a surface roughness of 6-20 nm, comparable to the 3D-printed masters (4-17 nm). Optical tests confirmed close to diffraction-limited focusing, and high-contrast and distortion-free imaging up to 161 lp/mm. Hybrid lenses maintained achromatic performance across 500-700 nm. Our method enables high-fidelity, cost-efficient mass production of freeform and hybrid micro-optics for imaging, sensing, and photonic integration.

Q 77.2 Fri 14:45 P 2

Compact 3D-printed dark-field condenser for high-resolution optical microscopy — •Robert Horvat[1], Leander Siegle[1], Luca Schmid[1], Pavel Ruchka[2], Philipp Flad[1], Monika Ubl[1], Michael Schmid[2], Lukas Wesemann[3,4], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Printoptix GmbH, Nobelstraße 15, 70569 Stuttgart, Germany — [3]School of Physics, The University of Melbourne, Victoria 3010, Australia — [4]ARC Centre of Excellence for Transformative Meta-Optical Systems, School of Physics, The University of Melbourne, Victoria 3010, Australia

We present a miniaturized, millimeter-scale dark-field condenser fabricated using femtosecond two-photon polymerization 3D printing. The device combines an annular absorbing aperture and a high numerical aperture lens on opposite sides of a glass substrate to enable oblique illumination for dark-field imaging. This compact condenser achieves strong contrast enhancement without bulky optics. We demonstrate its performance on USAF 1951 resolution targets, biological samples, and gold nanodisks below 300 nm, which remain invisible under collimated illumination. Our results pave the way for fully 3D-printed, cost-effective dark-field microscopy systems for applications in biology, medicine, and lab-on-chip devices.

Q 77.3 Fri 15:00 P 2

Interferometric wavefront characterization of 3D printed microlens singlets and doublets — •Yanqiu Zhao[1], Chris-Peter Winkler[1], Leander Siegle[1], Simon Thiele[2], and Harald Giessen[1] — [1]4th Physics Institute, Stuttgart, Germany — [2]Printoptix GmbH, Stuttgart, Germany

Femtosecond 3D printing allows for accurate fabrication of microoptics from diameters around 50 micrometers to millimeter scales. Characterizing the shape of printed singlet and doublet lenses is essential to quantify surface deviations caused by polymer shrinkage.

Confocal surface profiling allows z-deviation measurements down to 2 nanometers but loses accuracy on strongly curved surfacesand cannot reliably capture all surfaces or post lengths in compound lenses.

Therefore, we implement a lateral shear interferometer to actually measure the wavefront passing through the 3D printed microlenses, capturing both surface errors as well as refractive index variations from polymer density changes.

Combining confocal profiling with iterative wavefront interferometry, we demonstrate Strehl ratios above 0.97 with RMS wavefront errors around lambda/35 for singlets of over 600 micrometers diameter. For 3D printed doublets, we achieve Strehl ratios above 0.95 with RMS wavefront errors around lambda/28. Residual spherical aberrations are below lambda/100; residual coma and astigmatism values range around lambda/45.

This approach proves that 3D printed microlenses can compete with the best classically manufactured glass lenses up to a certain diameter.

Q 77.4 Fri 15:15 P 2

Characterization of thermodynamic properties of photoresist for 3D printing — •Fernando Lopez-Rodriguez, Robert Horvat, Leander Siegle, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

3D printing by two-photon polymerization for fabrication of micro-optical components is a widely used and a constantly developing field. The broad range of applications is continuously increasing, as 3D printing is adopted in areas from basic and applied science to manufacturing, quantum technologies, and bio-medical applications. Given the broad field of applications, optical and mechanical material properties, are of high interest. The thermal expansion coefficient alpha(T) and the refractive index n(T) are not known for most photoresists, especially at liquid helium temperatures, which are crucial for quantum applications. In our work, we present a micro-sized, on-fibre dilatometer device based on a 3D-printed Fabry-Pérot interferometer to measure the aforementioned properties over a large temperature range.

Q 77.5 Fri 15:30 P 2

Interferometric Measurements and Interative Metrology for the Shape Correction of 3D-Printed Microoptics — •Chris-Peter Winkler, Yanqiu Zhao, Leander Siegle, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

We present an interferometric measurement and optimization approach for 3D-printed aspherical singlet and doublet micro-optics fabricated by grayscale lithography. The transmitted wavefront is measured using a lateral shear interferometer, allowing us to reconstruct the corresponding surface height profile of the printed lens, including contributions from surface deviations due to shrinkage and refractive-index modulations arising from density variations in the polymer. The reconstructed wavefront is decomposed into the first 20 Zernike modes using a least-squares fit to identify the dominant aberrations and filter high-frequency noise. Based on this information, the lens height profile is iteratively corrected. Starting from an initial 0.8 λ spherical aberration, we achieve a Strehl ratio of 0.95 after a single optimization iteration for an aspheric singlet lens with 630 mum diameter

Q 77.6 Fri 15:45 P 2

Direct laser writing of in-volume diffractive optical elements with high speed and high resolution — Christian Ingenhag, Sebastian Stein, Aaron Schüller-Ruhl, and •Robert Fleischhaker — FH Aachen - University of Applied Sciences, Aachen, Germany

We report on a fast, high-resolution scheme to fabricate in-volume diffractive optical elements (DOEs) in fused silica by combining galvanometric beam scanning with a 0.4 NA microscope objective and a 1 ps laser. By exploiting nonlinear absorption and optimizing pulse energy for single-pulse writing, we achieve highly localized refractive-index modifications ($\Delta n \approx 5 \cdot 10^{-2}$) and feature sizes below the nominal focal spot. A layer-stacking scheme in z produces multi-level phase masks: examples are a 4-level, 250x250 px DOE with 2 μm pixels and a 10-level, 416x416 px DOE with 1.2 μm pixels. Phase-contrast microscopy verifies the written phase profiles, which closely match theoretical designs. Optical tests at 532 nm reproduce target intensity patterns with high fidelity (overlap $> 80\%$ against the computed discretized mask in a selected region and $> 66\%$ versus the original target). Rapid fabrication times (60 s for the 4-level device, 8-9 min for the high-resolution DOE) improve the trade-off between quality and speed toward practical applications.

Q 77.7 Fri 16:00 P 2

Fiber-based femtosecond 3D printing — •Anton Hellstern[1], Claudia Imiolczyk[1], Pavel Ruchka[1], Marco Wende[2], Theresa Kühn[3], Moritz Flöss[1], Michael Heymann[3], Andrea Toulouse[2], and Harald Giessen[1] — [1]4th Physics Institute, University of Stuttgart, Germany — [2]Institute of Applied Optics, University of Stuttgart, Germany — [3]Institute of Biomaterials and Biomolecular Systems, University of Stuttgart, Germany

Ultrashort laser pulses are often used in medical applications, for instance for soft-tissue surgeries. However, the progress on using such

laser pulses for additive manufacturing of tissue is rather marginal so far. Therefore, we aim to realize an endoscopic fiber-based femtosecond 3D printer to minimally invasively surgically repair organ damage on a micrometer scale. For this, high peak power femtosecond laser pulses are required, in order to 3D print the desired geometries using two-photon-lithography. By combining a grating compressor, a single-mode fiber, and suitable 3D printed microobjetives directly on the fiber tip, we achieve sub picosecond pulse durations which are able to polymerize both commercial photopolymers as well as bioinks. We report on dose tests, the optimization of printing speed, laser power, pulse compression ratio, and pulse duration. We demonstrate cell colonization of triply periodic minimal surface structures that represent scaffolds by printing 3D honeycombs and seeding them with living fibroblasts. This direct printing of cell scaffolds by endoscopic 3D printing will allow for endoscopic printing of bone tissue inside the body in the future.