Direct laser writing: Finer, faster and more flexible

E. Waller, M. Renner and G. von Freymann
Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, D-67663 Kaiserslautern, Germany
georg.freymann@physik.uni-kl.de

A. Radke and M. Thiel
Nanoscribe GmbH, Hermann-von-Helmholtz-Platz 1, D-76344 Eggenstein-Leopoldshafen, Germany

Direct laser writing is a versatile technique for the fabrication of three-dimensional nano- and microstructures and has become recently commercially available [1]. Applications range from cell-biology and microfluidics to three-dimensional nanophotonic structures [2]. For the latter one lateral feature sizes down to 100 nm or even below are desirable. This might be achieved due to two-photon absorption and the threshold behaviour of the photoresists. However, the finite numerical aperture (typically NA 1.4, oil immersion) of the objective lens focusing the ultrafast laser pulses into the photo sensitive material results in features which are axially elongated by more than a factor of 2.6 for conventional photoresists. This aspect ratio between axial and lateral feature size prevents lattice constants as small as the feature size, even before the diffraction limit hinders a further reduction.

To reduce the elongation, we employ a spatial light modulator to modify amplitude and phase distribution on the back focal plane of the objective lens. This allows to correct remaining aberrations in the setup and to display so called shaded-ring-filters (SRF). Combining both clearly reduces the aspect ratio from 3.2 in the uncorrected case down to 1.9 with aberration correction and SRF [3]. Spherical aberrations induced by focusing deep into the volume of photoresists usually counteract this correction already for small writing depths. To circumvent this, we use an index matched photoresist as immersion system in a so-called dip-in configuration, allowing for photonic crystals with several hundred layers without any observable degradation in feature size.

Writing times in serial writing processes are easily prohibitive for industrial applications. We reach a reduction by at least two orders of magnitude following two strategies: (i) Writing with several voxels in parallel reduces writing times by about one order of magnitude. It is crucial to employ algorithms taking into account phase and amplitude simultaneously to achieve truly identical voxels. Common phase-only algorithms fail for voxel distances below a wavelength of light due to interference effects. (ii) Scanning the beam instead of the sample reduces the writing time by another two orders of magnitude.

[1] see http://www.nanoscribe.de

[2] G. von Freymann et al., Advanced Functional Materials **20**, 1038 (2010)

[3] E. Waller et al., Optics Express **20**, 24949 (2012)