Fine structuring of integrated micro-optical components using lasers

Mangirdas Malinauskas, Etienne Brasselet, and Saulius Juodkazis

A new and accurate direct-writing technique employing linear processes can produce 3D structures of the highest resolution, quality, and fidelity.

Three-dimensional microstructures fabricated with lasers are increasingly used in photonics and across applications in light harvesting and biomedicine. For many years, researchers have employed a range of irradiation conditions in the search for an efficient and generic approach to making these structures. Direct laser writing in photopolymers using nonlinear absorption is a feasible solution. However, the necessity of using two-photon photoinitiators, whose absorption is resonantly tuned to the writing laser, rules out a number of substrate combinations due to chemical compatibility constraints. Moreover, most of the two-photon absorbing compounds are endowed with large benzene-cyclic structures to enhance the process of absorption and charge separation and are toxic. For more than a decade it seemed that the laser irradiation used for 3D structuring was material-specific, the material’s nonlinear absorption had to be engineered, and only femtosecond lasers could be used. All these requirements hampered the practical applications and industrial development of 3D laser structuring.

Now, there is increasing evidence that femtosecond laser polymerization at large and small repetition rates is compatible with 3D structuring at the highest resolution, quality, and fidelity. This indicates again that material spectral selectivity for two-photon absorption is not essential for 3D laser polymerization. Observations open the way for efficient structuring of photopolymers and glasses using linear absorption and thermal hot-spot writing/curing with simple continuous-wave/picosecond lasers. As a result, simpler and less-expensive fabrication setups are required, a welcome feature for practical applications.

Singular micro-optical elements enabling the control of individual features of light fields (such as helical beams that bear on-axis optical phase singularities and carry well-defined amounts of optical orbital angular momentum per photon) have been...
developed. The use of so-called spiral phase plates (SPPs), with complex transmittance involving linear azimuthal phase dependence, was first developed almost two decades ago. Such phase plates are now routinely replaced by spatial light modulators that consist of 2D electrically controlled pixelated liquid crystal centimeter-scale devices that cannot be straightforwardly downscaled to obtain optical vortex microgenerators. We previously reported an attempt to build microscopic 3D devices made of liquid crystal microdroplets. However, serious drawbacks remain. The macroscopic size of the arrays prevents them from being integrated into optical vortex generators. For example, there are limitations associated with the control of the spatial location of multiple micrometer-sized micro-optical elements as well as restrictions on the generation of optical vortices with topological charge different from 2.

We have fabricated micro-optical elements by 3D polymerization using a direct laser-writing technique. As an example, Figure 1(a) shows a 60/μm-diameter higher-order SPP as well as arrays of SPPs with arbitrary topological charge in a reliable manner and with good surface optical quality (better than λ/20 in the visible domain). The optical characteristics of our microscopic optical vortex generators have been fully characterized in terms of amplitude and phase spatial distribution: see Figure 1(b) and (c) for charge 1 and Figure 1(d) and (e) for charge 3 SPPs. In particular, we have validated the high fidelity of the obtained architectures by comparing the experimental results against simulations (see Figure 1).

We believe that direct laser polymerization will allow hybrid micro-optics that combine singular optical processing capabilities together with functionalities of either a refractive (lenses, prisms, axicons) or diffractive (gratings) nature. The versatility and applicability of the laser polymerization technique has already been proven by fabricating single optical elements of complex surfaces, including aspherical, Fresnel, and solid immersion lenses. This technique enables combined optical functions and hybrid refractive-diffractive optical elements to be integrated into already established technologies such as optical fibers. We successfully integrated a diffractive grating, a lens, and a prism onto the tip of an optical fiber (see Figure 2). This ability adds new functionalities in the fields of optomechanics, optofluidics, and sensors.

Our future work is aimed at developing functional micro-optics manufactured from optically active materials doped with fluorescent dyes or quantum dots. This would provide 3D integrated microstructures with lasing or routing capabilities that not only mimic traditional optical components at the microscale but offer novel functions for optically controlled microdevices.

Mangirdas Malinauskas acknowledges financial support from the European Commission’s Seventh Framework Programme (LASERLAB-EUROPE, 228334, OPTOBIO), and M. Farsari (FORTH, Heraklion) for providing photopolymer materials.

**Author Information**

**Mangirdas Malinauskas**
Vilnius University
Vilnius, Lithuania

Mangirdas Malinauskas is a researcher at the Laser Nanopolymerization Laboratory in the Laser Research Center. His current work focuses on the investigation of 3D direct laser writing in polymers and its application in micro-optics and photonics and the manufacture of biomedical and microfluidic devices.

Continued on next page
Etienne Brasselet
Université Bordeaux, LOMA, CNRA UMR 5798
Talence, France

Etienne Brasselet is a CNRS scientist at the Laboratoire Ondes et Matière d’Aquitaine at Bordeaux University. His current research activities focus on light-matter linear and nonlinear interactions in the presence of material and/or light field singularities with an emphasis on liquid crystal materials.

Saulius Juodkazis
Centre for Micro-Photonics
Swinburne University of Technology
Hawthorn, Australia
and
Melbourne Centre for Nanofabrication
Clayton, Australia

Saulius Juodkazis is a professor at Swinburne University and a technology fellow at the Melbourne Centre for Nanofabrication. His research is focused on mechanisms of light-matter interaction and on light harvesting and manipulation using 3D micro- and nanostructures.

References