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3D printing enabled by light and enabling the manipulation of light: feature issue introduction

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Abstract: This feature issue aims at highlighting the two-way connection between optics and photonics and 3D printing. One direction concerns novel photoresist materials and technical advances in optics-based 3D additive manufacturing. The other direction uses such advanced optical 3D printing technologies for the realization of novel micro-optical components, micro-optical systems, 3D artificial materials called metamaterials, micro-robots, and more. All of these would be difficult if not impossible to manufacture otherwise.

1. Introduction

Many promising approaches in 3D additive manufacturing a.k.a. 3D printing are directly based on light and on tailored photoreactive materials. A prominent example is two-photon or multi-photon absorption based 3D laser micro- and nanoprinting a.k.a. 3D direct laser writing. We are fortunate to have one of the pioneers of this technology, Shoji Maruo [1], on board of the guest-editor team for this feature issue. In turn, these rapidly progressing technologies enable the making of novel optical components and devices as well as the realization of other applications. A corresponding brief review and perspective has recently been given in [2].

Broadly speaking, the current challenges in the field of multi-photon 3D laser nanoprinting can be subdivided into improving the technology on the one hand and demonstrating novel applications on the other hand. In regard to technology, this means to improve the accessible spatial resolution, boost the printing speed, and make available more dissimilar material systems, including the possibility of stimuli-responsive material systems [3] (a.k.a. 4D printing) and many different constituent materials in one 3D multi-material structure.

The intricate interplay of optics and materials makes *Optical Materials Express* an ideal platform. With this feature issue, we do *not* intend to provide a collection of review articles. Comprehensive recent multi-author books are readily available already [4]. We rather intend to provide a platform showcasing selected latest developments and results in the field of optical 3D printing and its applications in optics and other areas.

2. About the papers in this feature issue

Therefore, we have planned all papers in this feature issue as contributed papers, except for one [5]. This work fits ideally to the spirit of this feature issue in that it not only uses advanced optics and materials for 3D laser nanoprinting, but also exploits this technology for applications

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in optics in terms of micro-optics and advanced miniaturized refractive multi-lens systems [6]. Without any post-processing, the lens surfaces that are 3D printed by using commercially available machine tools and photoresists exhibit a root-mean-square (RMS) roughness of only a few nanometers, truly qualifying as optical-quality surfaces [2,5,6]. The performance of these miniaturized refractive polymer lenses, which include the possibility of free-form surfaces and which can be 3D printed onto the end facet of an optical fiber or onto essentially any surface or prefabricated device, compares favorably with that of metasurface based lenses [7] in terms of spatial and chromatic aberrations in the visible spectral range. Some of the 3D nanoprinted micro-optical components are ready for specific industrial applications, for example for optical monitoring in catheters for minimally invasive surgery [6].

Aspherical lenses for fiber-optical micro-endoscopy in vivo neural imaging, minimally invasive diagnostics, and microsurgery are independently addressed in [8]. When going towards larger lenses, two issues have to be tackled. First, residual absorption by remaining photoinitiator molecules in the photoresist may lead to unwanted coloration, hence reduction of optical transparency. Second, stitching between different writing fields, determined by the finite field-of-view of the focusing optics, has to be dealt with. Both issues are addressed and impressively solved in [9].

However, the optical applications of 3D laser micro- and nanoprinting are not limited to sophisticated miniaturized lenses and lens systems. TiO_2-laden retinal cone phantoms can serve for calibration and characterization of optical coherence tomography instrumentation [10]. In addition, highly complex 3D printed multimode-splitters can serve for photonic interconnects [11]. Finally, architectures composed of a passive photoresist and a stimuli-responsive liquid-crystal elastomer allow for realizing pairs of whispering gallery mode optical resonators ("photonic molecules"), the distance between which can be controlled by temperature as the stimulus [12].

Regarding technological advances and novel materials, this feature issue covers four aspects. First, copper structures are written by laser reductive sintering within Cu_2O nanosphere films composed of Cu_2O nanospheres, polyvinylpyrrolidone, and 2-propanol [13]. Second, by writing lines of different metals into hydrogels, the resulting composite structures can be actuated by light in a manner that depends on the wavelength of light [14]. Third, an approach for multi-material 3D laser printing is presented based on using a pallet of photoresists [15]. As an example, multicolor structures are demonstrated. This pallet approach [15] represents an interesting alternative to previously introduced approaches based on integrated microfluidic chambers (see, e.g., [2]). Fourth, [16] uses optical fibers for multi-scale 3D lithography based on a photocurable ceramic slurry.

Disclosures

The authors declare that there are no conflicts of interest related to this article.

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