3D Optical Laser Lithography: No Limits?

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Abstract: Three-dimensional (3D) direct laser writing (DLW) can be seen as the 3D counterpart of planar electron-beam lithography. 3D DLW has become a commercially available workhorse (see, e.g., www.nanoscribe.de). However, DLW also used to be subject to certain seemingly fundamental limitations. In this review, we emphasize three aspects of recent progress.

(i) Stimulated-emission-depletion (STED) DLW is inspired by progress in optical microscopy (in Stefan Hell's group) and has led to spatial resolution beyond the Abbe diffraction barrier, especially in the problematic axial direction. For example, STED-DLW has enabled 3D polarization-independent visible-frequency broadband invisibility cloaks, visible-frequency 3D complete photonic-band-gap materials, and 3D gold quadruple-helix metamaterials.

(ii) By using the liquid photoresist as the immersion liquid, 3D "dip-in" DLW allows for structures with heights well beyond the free working distance of the microscope lenses used. For example, this has enabled pentamode mechanical metamaterials, which can be seen as elastic solids approximating the properties of liquids.

(iii) Galvo-mirror based DLW has boosted the accessible writing speeds by two orders of magnitude. For example, this has enabled the fabrication of 3D elastic core-shell "unfeelability cloaks" based on pentamode metamaterials. We have achieved samples with sub-micron feature sizes and, at the same time, overall volumes as large as 2 cubic millimeters. We have recently also successfully combined aspects (i) and (ii) and, independently, aspects (ii) and (iii).