3D Nanoprinted Multilevel Metalenses

RESEARCHERS

Koen Vanmol (koen.vanmol@vub.be), **Hugo Thienpont**, **Francesco Ferranti** and **Jürgen Van Erps**, Vrije Universiteit Brussel, Belgium

REFERENCES

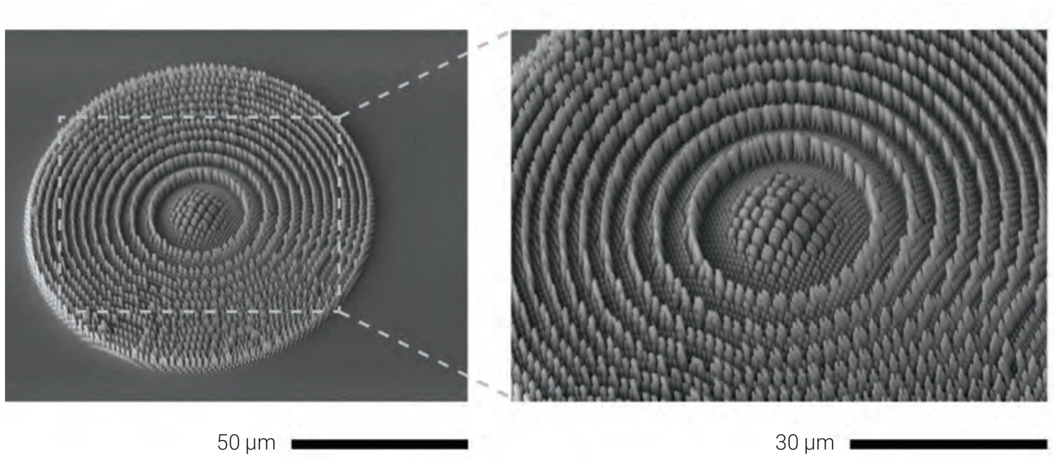
1. K. Ou et al. Nanomaterials **13**, 1235 (2023).
2. K. Vanmol et al., Opt. Express **32**, 10190 (2024).
3. G. Zyla et al. Laser Photonics Rev. **18**, 2301312 (2024).
4. Q. Liu et al. RSC Adv. **10**, 14274 (2020).

In the quest for the miniaturization and functionalization of micro-optical components, the ultra-thin metamaterials called metasurfaces have created a field with broad applications. These artificially engineered surfaces, which consist of subwavelength nanostructures distributed in a lattice of unit cells, can be designed to realize unique electromagnetic field modulation, leading to unprecedented control of light properties. The ability to tailor these compact surfaces and create highly customizable flat optics opens opportunities for their integration in multiple areas, such as telecommunications, sensing, imaging and biomedicine.[1] Examples of such metasurfaces include ultra-thin achromatic lenses made of a single material, hologram generators that create specific field distributions and anti-reflection coatings working in different wavelength regimes.

Most metasurfaces are currently fabricated using high-resolution photolithography, focused-ion-beam milling, or electron-beam lithography, so their geometric design is usually limited to only two dimensions, since they have a fixed height. In our recent work,[2] we demonstrate the unique 3D direct-laser-writing capabilities of two-photon polymerization (2PP) technology,[3] which offers an extra degree of design freedom along the vertical direction. Using the 2PP technology, we were able to achieve sub-micrometer unit cell dimensions with an optimized reproducibility of the nanostructure shape, allowing the creation of high-numerical-aperture multilevel metalenses.

Our metalens design consists of multilevel nanopillars based on the natural ellipsoidal voxel shape of the laser scanner's focal spot. By creating nanopillars with varying heights, we can locally modulate a light beam's phase profile across the metasurface. We showed the versatility of this methodology by 3D printing multiple metalenses on flat substrates and on optical-fiber tips. We also demonstrated that our process is capable of creating 2PP metalenses with a record-high numerical aperture of 0.96, effectively focusing light to a subwavelength spot size of 0.84 λ (full width at half maximum) at the telecom wavelength of 1550 nm. Additionally, the focusing efficiency can be as high as 31.8%.

We believe that the 2PP technique has become a reliable and valuable technology that is complementary to traditional lithographic techniques, enables *in-situ* printing of high-quality 3D nanostructures and allows the prototyping and fabrication of high-performance metasurfaces. In addition to their use in optical interconnects and imaging applications, 3D-nanostructured metasurfaces could in future leverage existing sensing methods. Furthermore, the enhanced light–matter interaction with the subwavelength features could lead to advanced functionalities and novel properties in optical measurement systems.[4] OPN



High-numerical-aperture multilevel metalens fabricated through two-photon polymerization.