Sustainable Manufacturing of Optical Metasurfaces for Imaging, Sensing and Display

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Short Summary
Metamaterials and metasurfaces are nanostructure arrays enabling near-diffraction-limit imaging across UV to infrared wavelengths for microscopy, 3D sensing, and displays. While offering functionalities like tunable focusing and trichannel imaging, their commercialization faces manufacturing challenges. Recent advances in lithography provide scalable production solutions.

Full Abstract
Metamaterials and metasurfaces have emerged as revolutionary optical components composed of engineered nanostructure arrays. These innovative structures offer unprecedented advantages through their ultracompact form factor and ability to image submicron objects with near-diffraction-limit resolution[1,2]. Their applications span an impressive range from conventional microscopy[3] to cutting-edge technologies including 3D sensors[4,5], LiDAR systems[6], bio-imaging devices[7,8], and advanced cameras[9]. The operational wavelength range of these devices continues to expand, enabling diverse applications across the electromagnetic spectrum. In the UV region, metalenses achieve superior resolution imaging[10], while in the visible spectrum, they show promise for VR/AR display applications[11]. Near-infrared metalenses find applications in night vision devices and medical endoscopes[12], while their utility extends into the ultrasound region for photoacoustic microscopy[13,14]. Recent advances have also demonstrated their potential in energy harvesting through elastic metalenses[15] and sound wave focusing via acoustic metalenses[16].
These metasurfaces exhibit remarkable functionalities, including tunable focal lengths[17], trichannel imaging based on spin states[18], and even single-photon imaging capabilities[19]. However, their widespread commercialization faces significant challenges, particularly in terms of scalable manufacturing and cost-effective production. To address these limitations, several innovative approaches have been developed. Nanoimprint lithography, enhanced with high-refractive-

index particles, offers a promising one-step printable platform[20-22]. ArF photolithography has emerged as a solution for high-throughput, large-area metasurface production at the wafer scale[23]. To further optimize production costs, recent research has focused on combining these methods, utilizing wafer-scale nanoimprint technology to replicate metasurfaces initially created through photolithography[10,11]. These advanced manufacturing strategies represent crucial steps toward transitioning metalenses from laboratory demonstrations to practical, commercially viable applications in imaging, sensing, and display technologies[24,25].

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