Wafer-scale manufacturing of centimeter-sized metasurfaces down to the deep-ultraviolet region

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UV optics play a vital role in both science and technology, from spectroscopy and quantum optics to photolithography and biosensing. Conventional UV optics are primarily based on bulky optical components and have limited functionality and diversity. As an alternative, metasurfaces can provide fine wavefront-shaping platforms with a compact form-factor, resulting in drastic miniaturization of the device and capability of diverse functionality. However, metasurfaces operating in the UV regime face long-standing challenges, such as the scarcity of low-loss and high-index UV materials and patterning limitations (small patterning area, high cost, and low throughput). Recently, UV-transparent materials such as zinc oxide [1], silicon nitride [2], and hafnium oxide [3] have been actively studied; however, the fabrication process of these materials is not scalable or easy to manufacture because they include e-beam lithography and multi-step etching with thick layer deposition. Recently, our group developed a scalable manufacturing platform that can produce visible metasurfaces on the wafer scale [4]. However, a UV-transparent material compatible with our scalable method and patterning resolution remains a challenge for scalable manufacturing of UV metasurfaces. In this work, we fully address this long-standing challenge and mass-produce centimeter-scale UV metalenses by introducing a zirconium dioxide (ZrO_2)–polymer hybrid material and high-resolution ArF photolithography. We find that ZrO_2 has both a high refractive index and low absorption in the UV regime, and is compatible with our scalable method using atomic layer deposition (ALD). Using scalable and easily manufacturable ZrO_2–polymer hybrid material, we succeed in mass-producing centimeter-scale UV metalens for the first time. Owing to the high repeatability of nanoimprint lithography, our method can fabricate wafer-scale UV metalenses at extremely low cost and high throughput. Notably, thin-film coatings in hybrid materials enable strong light confinement, resulting in high efficiency of fabricated metalenses. The proposed method fully addresses the long-standing challenges in the field of UV metasurfaces and presents a practical possibility for the first time that UV metasurfaces can be applied in real life.

Reference

[1] ***Sci. Adv.* 8**, abn5644, 2022
[2] ***ACS Nano* 16**, 3546-3553, 2022
[3] ***Light Sci. Appl.* 9**, 55, 2020
[4] ***Nat. Mater.* 22**, 474-481 (2023)