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Laser micromachining with a large-aperture metalens for a 1064-nm nanosecond laser

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Laser micromachining with a micrometer-scale focal spot by an ultrashort-pulse laser is a powerful technique for fabricating electronic and optical devices because it combines broad material compatibility with non-contact processing [1-2]. In most implementations, tight focusing is achieved with objective lenses. However, conventional objective lenses are bulky and have short working distances, which constrain the optical layout and limit access to recessed regions or geometrically complex workpieces. Their limited incident pupil diameter further restricts the use of high-intensity ultrashort-pulse lasers under practical damage-threshold constraints.

Metalenses are planar optical elements that control wavefronts through sub-wavelength structures. They have recently been developed and are expected to serve as new functional focusing lenses [3]. Because metalenses can be fabricated lithographically, they can integrate a

thin form and a large aperture within a single optical element. These features have motivated growing interest in their use for ultrashort-pulse laser processing [4]. However, it remains unclear whether they are applicable to 1-μm-band nanosecond laser sources, which are widely used in industrial laser processing. Here, we demonstrate laser micromachining using a large-aperture metalens for a 1064-nm nanosecond laser.

We designed and fabricated a metalens for 1064 nm light by integrating pillar and diffraction-grating structures, as shown in Fig. 1a. The metalens had a 22 mm aperture and an 11.5 mm working distance, corresponding to a numerical aperture of 0.7. Focusing measurement at 1064 nm yielded a focal spot diameter of 1.5 μm (FWHM). Figure 1b shows scanning electron microscope (SEM) images of micro-holes fabricated in silicon using 1064-nm, 10-ns laser pulses focused by the metalens and a commercial objective lens. The results indicate that the morphologies fabricated by the metalens are comparable to those obtained with the commercial objective lens. We also demonstrated logo patterning at recessed locations that are difficult to access with a conventional objective lens by engraving the logo on the camera sensor plane inside a package, as shown in Fig. 1c. These results demonstrate that large-aperture metalenses are promising focusing elements for laser micromachining.

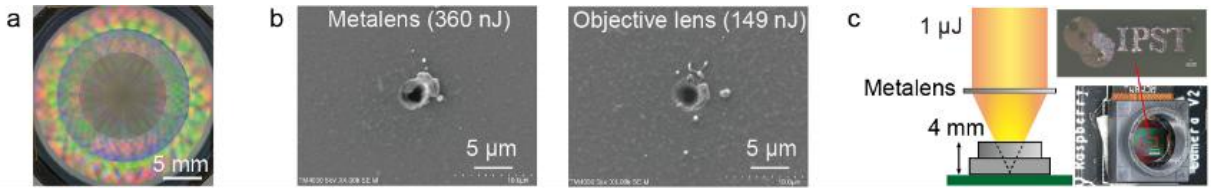

Figure 1: a, Optical microscope image of the fabricated metalens. b, SEM images of fabricated micro-holes. c, Logo patterning on the camera sensor surface inside the package.

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