Transfer and Integration of Optical Metasurfaces

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Optical metasurfaces and planar optics provide wavefront manipulation within a sub-wavelength distance, which hold great promise for miniaturizing optical systems with a reduced footprint and improved functionality[1,2]. However, metasurfaces have mostly been demonstrated on conventional bulky and planar substrates, which are often orders of magnitude thicker than the metasurface itself. It not only cancels the miniaturization advantage enabled by metasurfaces, but also limit their application scenarios. For more practical applications and wider adoptions, there is a pressing need to develop transfer techniques for heterogenous integration of metasurfaces with various electronic and photonic devices. For example, metasurface integrated on optical fiber tips will improve the compactness and precession of endoscopic devices for imaging and sensing applications[3]. Most existing works rely on either gluing a metasurface on glass substrate onto a fiber tip[3] or direct etching of gold metasurfaces on a fiber tip using focused ion beam[4].

Here, we demonstrate a universal metasurface integration technique, composed of a polymer-assisted transfer process and a micro-punching process with alignment under microscope (Fig. 1). There are two variations of our techniques, where the metasurface is either embedded in a spin-coated polymer layer (Fig. 1a), or on a pre-coated polymer layer (Fig. 1b) respectively, both on top of substrates with sacrificial layers. Metasurfaces are fabricated by standard electron beam lithography. An aperture structure is opened in the polymer (resist) layer by lithography, with the metasurface aligned to the center of the aperture. After the underlying sacrificial layer is dissolved, a free-standing polymer membrane is released and picked up by a frame (Fig. 2a). Under microscope, an optical fiber (Fig. 2b) is aligned to the aperture and punched through the polymer membrane. The metasurface is detached from the membrane and attached on top of the fiber tip. The adhesion can be improved by thermal annealing process. Following the proposed nanofabrication and micro-punching process, an integrated metasurface on fiber tip was successfully demonstrated (Fig. 2c). The optical function of a TiO_2 focusing metalens was also validated after the transfer process[5]. This technique will enable heterogenous integration of metasurfaces with a variety of devices including optical fibers, modulators, sensors, actuators, etc.

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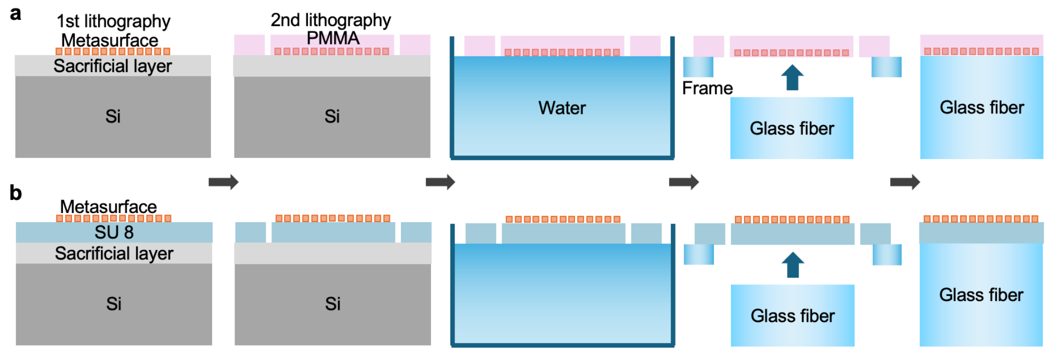

Figure 1: Metasurface nanofabrication, transfer and integration process. (a) Metasurface embedded in a spin-coated polymer layer (PMMA). (b) Metasurface on top of a pre-coated polymer layer (SU 8).

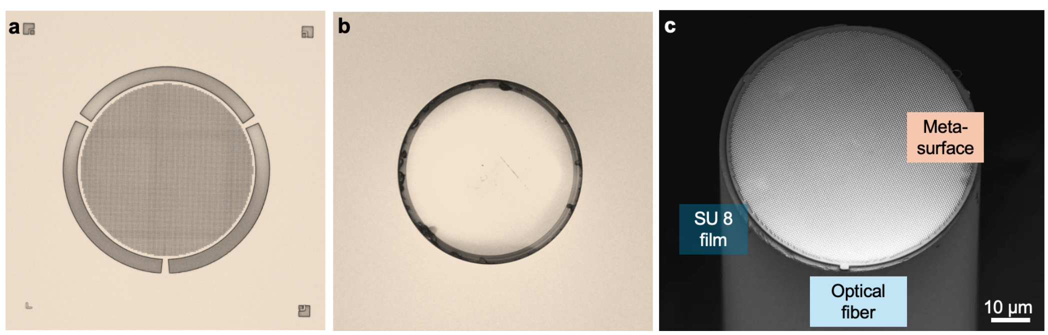

Figure 2: Experimental demonstration of metasurface transfer and integration on an optical fiber tip. Optical microscope images of (a) a metasurface on a free-standing SU 8 membrane with aperture and (b) an aligned optical fiber. (c) SEM image of a metasurface successfully integrated on top of a fiber tip.