Nanometre-Scale Fabrication of Optical Metasurfaces Using Helium Ion Milling

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The study of metasurfaces has seen innumerable unit cell designs – from simple to extremely complex – with electrically small unit cells and features mere hundredths of a wavelength in size. There has been a push to fabricate such designs in the optical domain to realize phenomena such as planar lensing, exotic beam forming and anomalous refraction. Unfortunately, fabricating structures at such a high resolution is nearly impossible due to a requirement for thick (optically opaque) films and hence, high aspect ratios. Conventional mask-based nanopatterning techniques include liftoff, which cannot create high-aspect ratio features due to deposition difficulties, and many forms of etching, which are generally isotropic processes for well-behaving metals such as gold. As a result, researchers have focused on simple structures with other interesting physics, such as plasmonic nanoparticles and nanowires, and nanohole arrays that demonstrate extraordinary transmission.

In this work, we will show that by using state-of-the-art helium ion beam milling techniques, metasurfaces can be made with 10 nm or better resolution and 5:1 or better aspect ratios. We will discuss the proper fabrication process required to overcome problems such as redeposition, drift, ion-activated reactions, over- and undermilling, and material sensitivity. As a proof of concept, the developed process will be applied to create a metascreen (M. Semple, A. C. Hryciw, and A. K. Iyer, 2017 MRS Fall Meeting, Boston, MA) with finely patterned apertures for operation at 1550 nm wavelength. The metascreen has a pitch of $\lambda/5$, an aperture size of $\lambda/6$, a minimum feature size of $< \lambda/155$, and a 6:1 aspect ratio. Figure 1 shows the achieved resolution of this process, for an array pitch of 300 nm, an aperture size of 243 nm, and a minimum feature size of 8 nm.

The extremely small features achievable by this process, when applied to noble metals such as gold, allow strong plasmonic field confinement, which may be used to strongly excite nonlinearities in materials or to increase sensing thresholds. The extremely subwavelength features may also be used to create complicated resonant structures with further miniaturization than conventionally available.

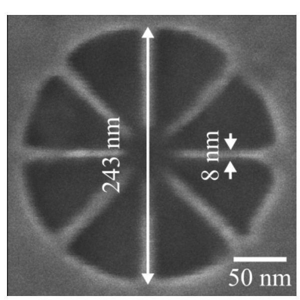

Figure 1: A fabricated metasurface unit cell