Asterisk-Shaped-Aperture Array Optical Metasurfaces at Telecommunications Wavelengths

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Aperture arrays in metal films have been subject to intense study due to the many peculiar transmission, reflection and confinement phenomena they can produce. Plasmonic aperture arrays have found several notable applications in surface plasmon sensing, surface enhanced spectroscopy and subwavelength imaging. Unfortunately, conventional aperture arrays often rely on resonance mechanisms that require aperture size and/or spacing on the order of a wavelength, and therefore, electrically large arrays. Miniaturizing these dimensions to a sub-wavelength scale would result in compact arrays that would enable sub-wavelength spatial sensing and/or imaging applications, and allow for higher aperture-array device density in a given area. Further, sub-wavelength aperture sizes and periods suggest that such a periodic surface could be called an optical metascreen (MTS), with which planar lensing and beam shaping could be accomplished.

Recently, it was experimentally shown that lining each aperture with a thin metamaterial exhibiting epsilon-negative and near-zero (ENNZ) properties introduces a resonant transmission peak well below both the natural fundamental transmission frequency and grating anomalies for an array of commensurately sized unlined apertures. This allows the apertures to be small while also being packed tightly together. These MTSs have been translated to optical frequencies, and employ plasmonic ENNZ liners that allow subwavelength spatial control of fields for the realization of new optical phenomena or the enhancement of optical devices. For example, laser mirrors could be created with subwavelength control over phase and magnitude, subwavelength spatial information could be added to plasmonic sensors and pixels arrays, and, with the use of non-linear materials, compact and bistable photonic switches could be made for optical telecommunications.

In this work, we establish that an asterisk-shaped aperture MTS is akin to the ENNZ-aperture-based MTS discussed in (M. Semple et al., "Optical implementation of a miniaturized ENNZ-metamaterial-lined aperture array," IEEE 2017 Antennas and Propagation Symposium (San Diego, CA, USA), July 2017). The design was simulated using COMSOL Multiphysics with minimum feature sizes of 10 nm, as achievable by helium focused ion-beam (He-FIB) fabrication. The aperture array was designed to transmit at $\lambda = 1.55$ μm (f = 193 THz). We shall also present complementary metafilm (MTF) structures, which show analogous, but inverted, beam reflection and transmission properties compared with their aperture-based MTS counterparts. The two constitute a set of novel metasurface topologies, with applications spanning the terahertz through optical regimes.