Dense metasurface with high efficiency for broadband optical vortex by high resolution electron beam lithography

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Metasurface is capable of manipulating the polarization/phase status of light by transferring a Gaussian beam into an optical vortex beam. Optical vortex beams possess orbital angular momentum (OAM) of the photons, which is prospective in broad applications in astronomical filters, quantum optics, optical microscopy to optical tweezers. However, vortex beams generated by metasurfaces currently suffer from two drawbacks: low efficiency and narrow waveband, hindering the practical use. Conventional methods for improving the efficiency are mainly by multiple layers of metals, metal-insulator-metal (MIM) stacks, high refractive index dielectric materials and so on. These methods require complicated structures, lengthy fabrication and high cost with limited prospect for large scale manufacture.

In this work, we propose a new approach by using high density of nano antenna array in a single layer of Al with 210 nm in arm length and 50 nm in arm width, as illustrated in Fig. 1, which is able to generate high-efficiency optical vortex beam in visible frequency range. Systematic Finite Difference Time Domain (FDTD) simulations show the conversion efficiency is enhanced up to over 40% in the wavelengths from 540 nm to 720 nm, when the pitch of antennas is reduced from 500 nm to 200 nm. A thicker layer of Al also contributes to the better conversion efficiency in a broader range of wavelengths as shown in Fig. 2 and 3. The structures in Fig. 4 are fabricated by Electron Beam Lithography (EBL) by a JEOL-6300FS system followed by a thermal metal deposition. The on-going optical measurements with the setup in Fig. 1 are being carried out. In conclusion, a novel high density metasurface with thick Al elements are fabricated, aiming at achieving high-efficiency optical vortex conversion in broadband in visible frequency. This is an essential step for metasurface to find broad applications in communication encryption, optical microscopy and optical tweezers.

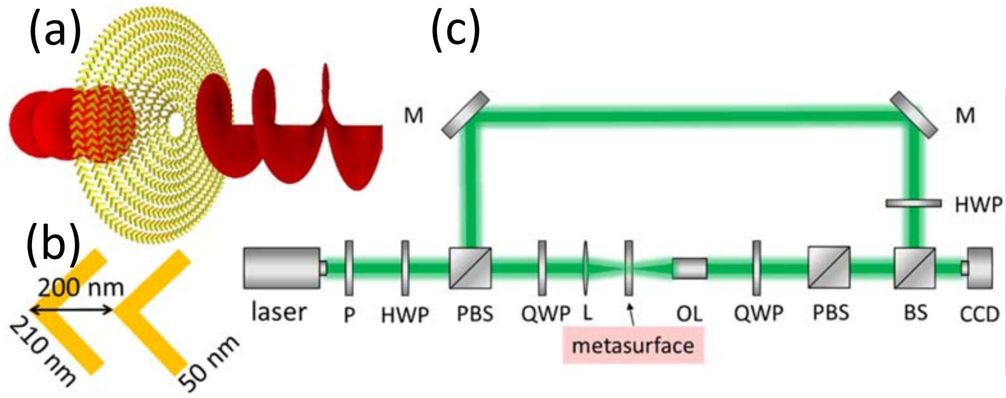

Figure 1: (a) a plane Gaussian beam is converted to an optical vortex beam after passing through the designed dense metasurface structures with elements arranged in concentric rings. (b) The element of the metasurface has two arms perpendicular to each other with 210 nm in length and 50 nm in width. (c) The setup for interference measurement to observe the optical vortex beam. P: polarizer; HWP: half wave plate; PBS: polarizing beam splitter; QWP: quarter wave plate; L: lens; OL: optical lens; BS: beam splitter; M: mirror.

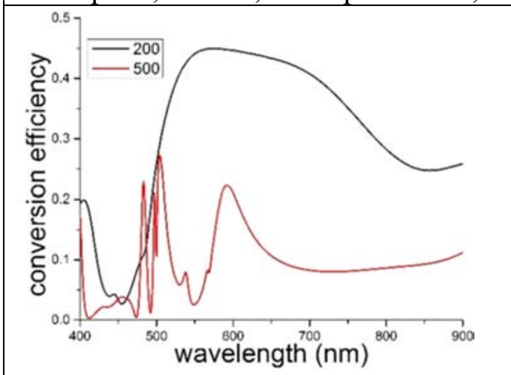

Figure 2: The FDTD simulated optical vortex conversion efficiency through the metasurfaces consisting of 90 nm thick Al elements with the period of 500 nm and 200 nm.

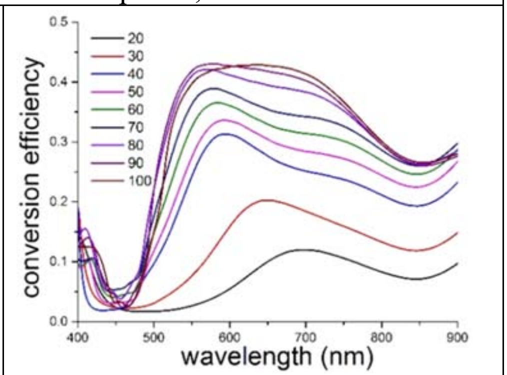

Figure 3: The simulated optical vortex conversion efficiency through the metasurface consisting of Al elements with a period of 200 nm and thickness ranging from 20 nm to 100nm.

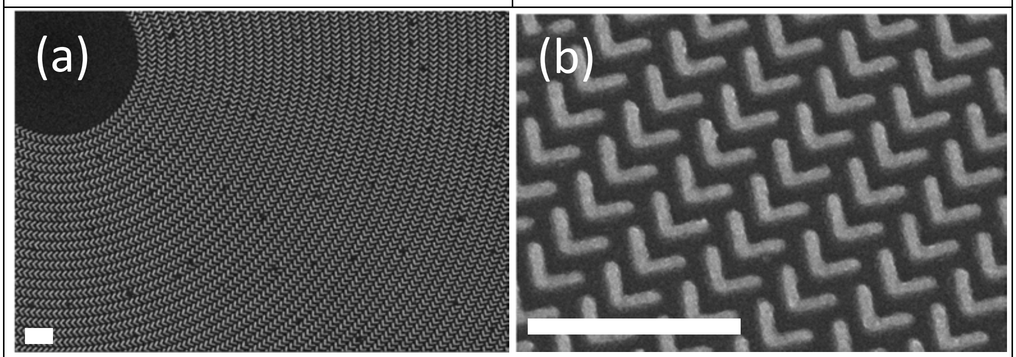

Figure 4: The EBL fabricated metasurface consisting of 60 nm thick Au elements with a 200 nm period. The scale bars in the pictures are 1 μm.