Enhancing the conversion efficiency of spin-to-orbit angular momentum by nanoscale metasurface reconstruction

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Metasurfaces with metallic nanostructures are able to transform a plane wave into a spiral wave by converting the photon spin angular momentum (SAM) into its orbital angular momentum (OAM), leading to broad applications in astronomical filters, quantum optics, optical microscopy and optical tweezers. Unfortunately the conversion efficiency is only around 5-10%, which are practically inapplicable. The main problems lie in the defects in the nanostructures, the low pattern density and the unsuitable materials. To enhance the conversion efficiency, efforts should be made to develop advanced nano-fabrication techniques for well-defined nanostructures in ultra small scale with high pattern density on adequate materials with excellent plasmonic property.

In this work, we propose a densely arranged nano antenna array with L-shaped Al elements arranged in concentric rings on the quartz substrate with 210 nm in arm length and 50 nm in arm width, as illustrated in Fig. 1. State-of-the-art electron beam lithography was carried out with a JEOL-6300FS system in the PMMA resist at 100 keV as the acceleration voltage and 500 pA as the beam current. After the thermal deposition of a 100 nm thick Al on the replicated pattern, a high quality metasurface with high density L-shape elements was fabricated, as shown in Fig. 2. The pattern was carefully designed by systematic Finite Difference Time Domain (FDTD) simulations as presented in Fig. 3 to obtain the optimized thickness and period for the metasurface. From the simulations conducted, it is concluded that the metasurface with the Al thickness of 90 nm and the period of 200 nm is capable of achieving a conversion efficiency as high as over 40% in a broad wavelength range from 540 nm to 720 nm. The optical measurement results shows a consistent conversion efficiency of >20% over a wide visible wavelength range, among which the donut-shaped light spots of the vortex beams are captured for the wavelengths of 532 nm and 638 nm in Fig. 6. This is an essential step for the metasurface to find applications in communication encryption, optical microscopy and optical tweezers.

By summary, this paper reports an important advance in the design and the reconstruction of metasurfaces for manipulating optical field in visible frequencies with significantly enhanced frequency. As high as 25% of the efficiency has been achieved. This work shines a bright light on the further development avenue for realizing practically applicable metasurface.

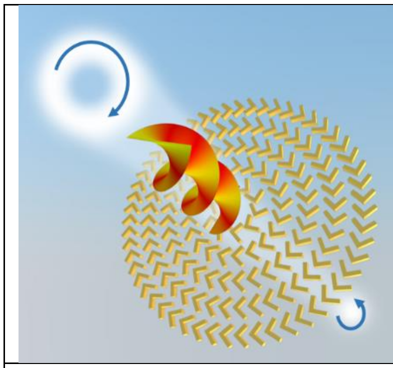

Figure 1: The plasmonic metasurface is capable of flipping the incoming left/right circular polarized (L/RCP) light into R/LCP, generating orbital angular momentum for the vortex beam.

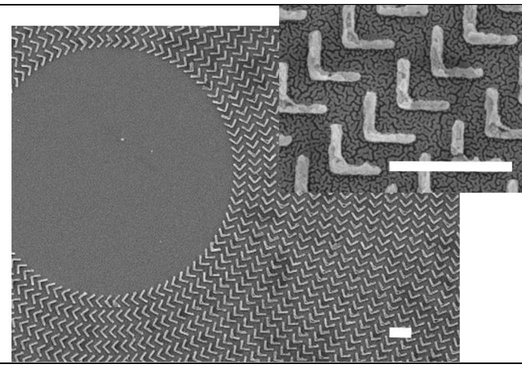

Figure 2: The scanning electron microscope (SEM) pictures of the fabricated Al plasmonic metasurface on the quartz substrate. The scale bar in both pictures is 500 nm.

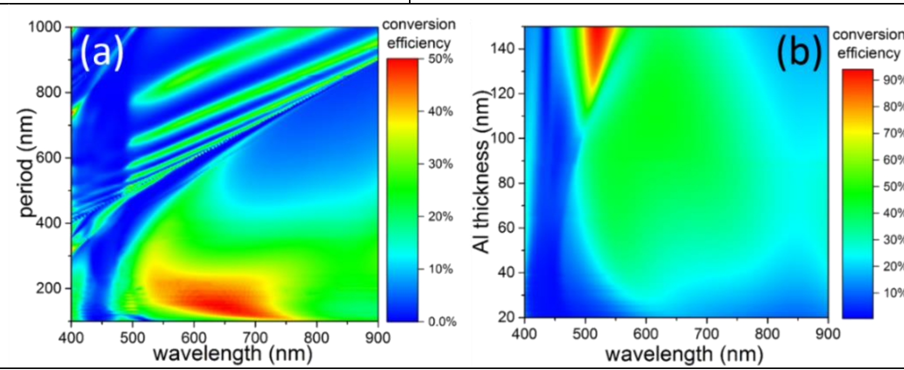

Figure 3: The FDTD simulated conversion efficiency for the period and Al thickness of the nano-antennas on the metasurface. The optimized the period is 200 nm and the thickness is 100 nm.

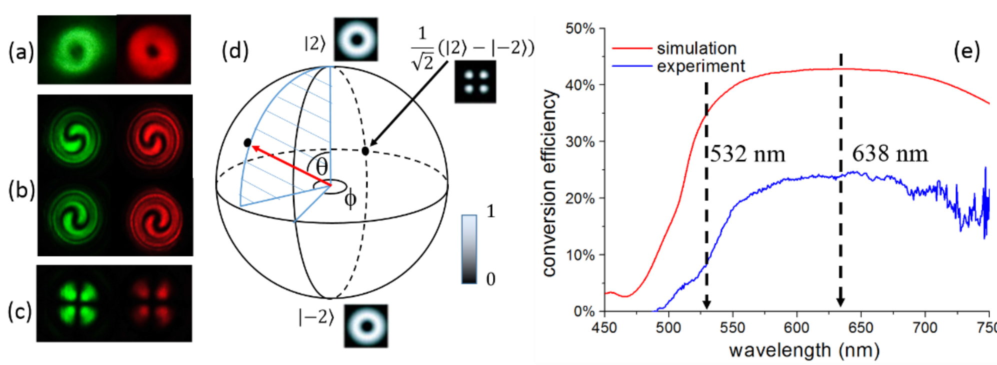

Figure 4: The photos of the (a) obtained donut-shaped vortex beam, (b) the interference pattern of the vortex and the L/RCP light, and (c) the interference pattern of two beams of optical vortex. (d) The shapes of the vortex beams shown on the Poincar ésphere of the OAM. (e) The FDTD simulated and spectrometer measured conversion efficiency of the plasmonic metasurface in the visible spectrum with high efficiency over a broad waveband.