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Observing Nanoscale Orbital Angular Momentum in Plasmon Vortices with Cathodoluminescence

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Light possessing orbital angular momentum (OAM) is currently a topic of significant interest in nanophotonics. Optical OAM possesses a helical wavefront and orthonormal momentum basis set that have been utilized in applications such as optical manipulation and trapping as well classical and quantum communications [1,2].

Incorporating OAM into nanostructures presents great opportunities for on-chip technologies, but also poses significant challenges in terms of the observation and analysis of nanoscale optical phenomena. Near-field scanning microscopy (NSOM) has been used recently to great success to study nanoscale OAM effects [3]. However, this technique relies on discrete, monochromatic optical excitations, and for many advanced applications, the dispersion and spectral dependence of the OAM mode can have significant effects on the optical transitions in the system [4]. To this end, cathodoluminescence (CL) provides a unique opportunity to combine (and enhance) the nanoscale spatial-resolution of NSOM along with accessing the full spectral response of the material.

Here, we employ CL within a VG-HB601 scanning transmission electron microscope (STEM) operated at 60 kV to study OAM in plasmon vortices. The system used to generate the plasmonic vortices is a spiral channel in a metallic film, an example of which can be seen in Figure 1a. The sample is prepared by evaporating a silver film onto an electron-transparent SiN membrane; the spiral channel is then milled into the silver film using a focused-ion beam. The spiral channel geometry is defined by the equation $r(\theta)=r_0+d\cdot\theta$, where r_0 is the initial radius, θ is an azimuthal coordinate, and d is the distance between the arms of the spiral. In this system, surface plasmon polaritons (SPPs) from along the inner-edge of the spiral coherently interfere within the spiral arms. If the spiral arm spacing is equal to the initial spiral channel radius r_0, a plasmon vortex is formed at the wavelength where $\lambda_{SPP}=r_0=d$.

Figure 1b shows a spectrum image (SI) of the spiral channel in 5 nm wavelength bins at four different wavelengths 460 nm, 560 nm, 660 nm, and 760 nm. At the low- and high-wavelength extremes, interference between SPPs is observed, but the plasmon vortex is not present. However, at 560 nm and 660 nm, the CL response distinctly converts to spiral arms that emanate from the origin of the spiral, a characteristic sign of a plasmon vortex.

CL-SI provides not only a nanoscale description of the plasmonic vortex, but a spectrally resolved one as well, and provides a nm-by-nm picture of the dispersion of the vortex across the visible regime. Further, STEM-CL studies illustrate changes in the topological charge of the OAM mode, and can be used to observe near-field interactions between the plasmon vortex and chiral substructures, demonstrating the spatial and spectral resolution available via STEM-CL to study OAM in nanostructures.

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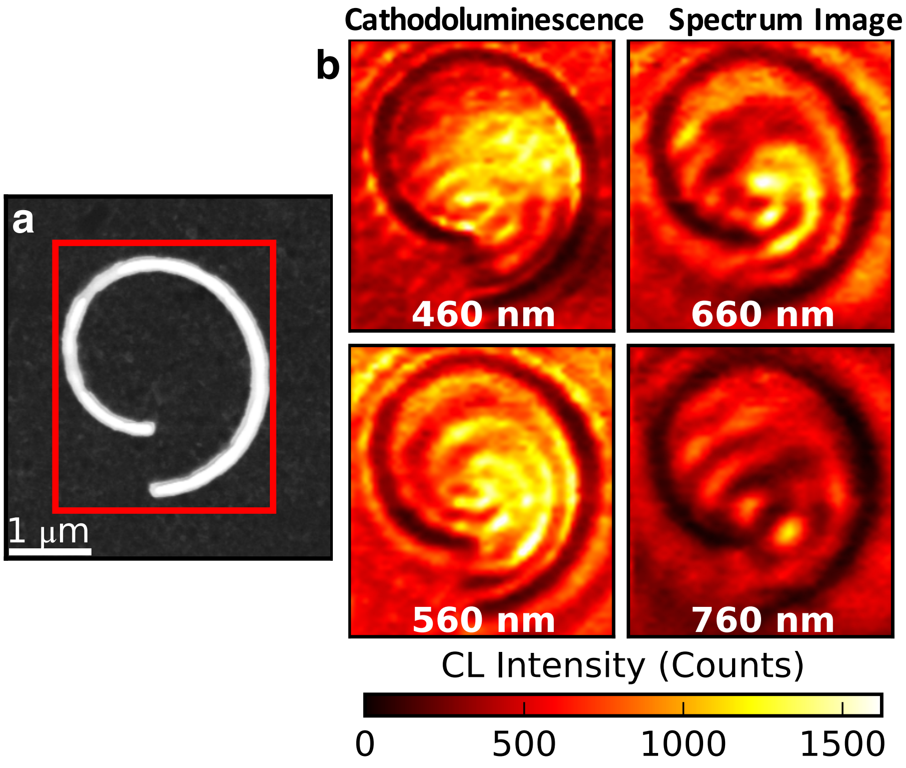

Figure 1. (a) BF-STEM image of spiral channel in silver film, with spectrum image region marked by a red square. (b) STEM-CL spectrum image shown in 5 nm wavelength bins at 460 nm, 560 nm, 660 nm, and 760 nm showing the formation of the plasmonic vortex.

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