An attempt to map the electromagnetic field from plasmonic nanostructures using differential phase contrast and electron holography

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Surface plasmon resonances (SPRs), the collective oscillations of conduction electrons confined in a nanostructure, are of interest for their uses in engineering the optical properties of materials through their unique ability to manipulate light on the nanoscale. Depending on the chosen shape of the nanostructure, SPRs are commonly used to create electric or magnetic dipole moments under incident light. The toroidal dipole moment, created from circulating magnetic fields, can also be created with SPRs and is of particular interest for its non-reciprocal interactions with light [1]. The necessary configuration of circulating magnetic fields can be created using four upright split-ring resonators, each of which creates an in-plane magnetic dipole moment [2].

Of great interest in studying the nature of SPRs is the ability to experimentally characterize the electromagnetic fields created by the SPRs. In the electron microscope, the electric fields parallel to the electron beam can be detected through high resolution electron energy loss spectroscopy (EELS), but detecting fields perpendicular to the electron beam remains a significant challenge due to the oscillatory and short-lived nature of the SPRs.

In this study, an attempt to characterize the in-plane electromagnetic field distribution of SPRs in a toroidal nanostructure is shown (Fig. 1 a) and b)). Two different methods are tested: differential phase contrast (DPC), i.e., recording the deviation of the electron beam in the diffraction plane which is caused by the electromagnetic fields; and electron holography (EH), i.e., recording the interference between two electron beams crossing different electromagnetic field configurations. Experimental results (examples shown in Fig.1 c) and d)) are presented, and a physical interpretation is proposed including the contribution of the substrate in the electrostatic field distribution. Challenges remain in detecting the signal from the SPRs over background, noise, and the contribution from the substrate charging.

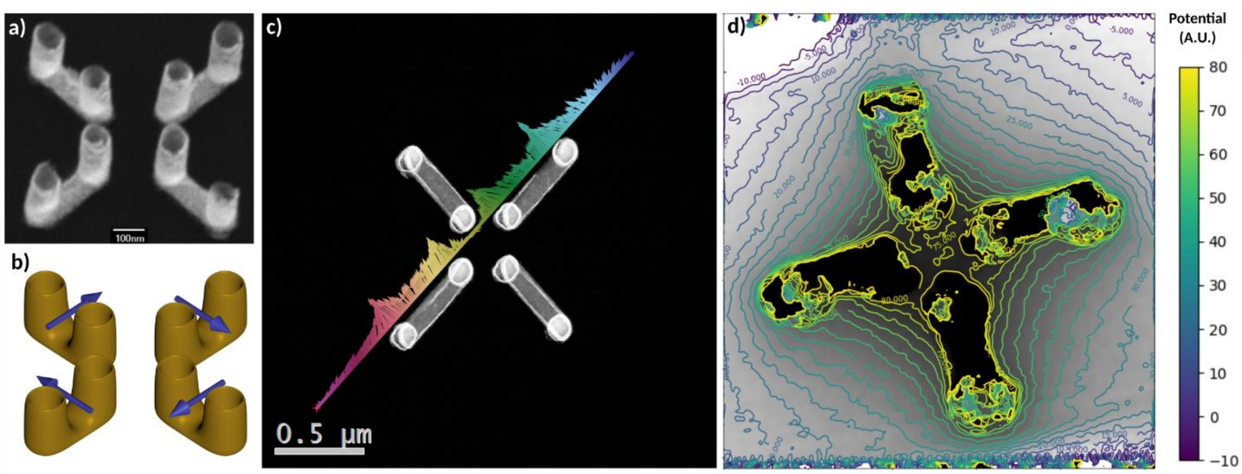

Figure 1: a) SEM electron micrograph highlighting a typical toroidal nanostructure. b) Schematic diagram of the toroidal nanostructure with the expected in-plane magnetic field (purple arrows) of the toroidal dipole moment. c) DPC line profile recorded near the toroidal nanostructure. The arrows represent the deviation (not to scale) of the electron beam from the optical axis. d) Potential map in arbitrary units calculated from an EH recorded on the toroidal nanostructure.

References

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[2] I.C. Bicket *et al.,* "Correlative electron energy loss spectroscopy and cathodoluminescence spectroscopy on three-dimensional plasmonic split ring resonators", *Microscopy*, 2018. *In press*, DOI: 10.1093/jmicro/dfy010.