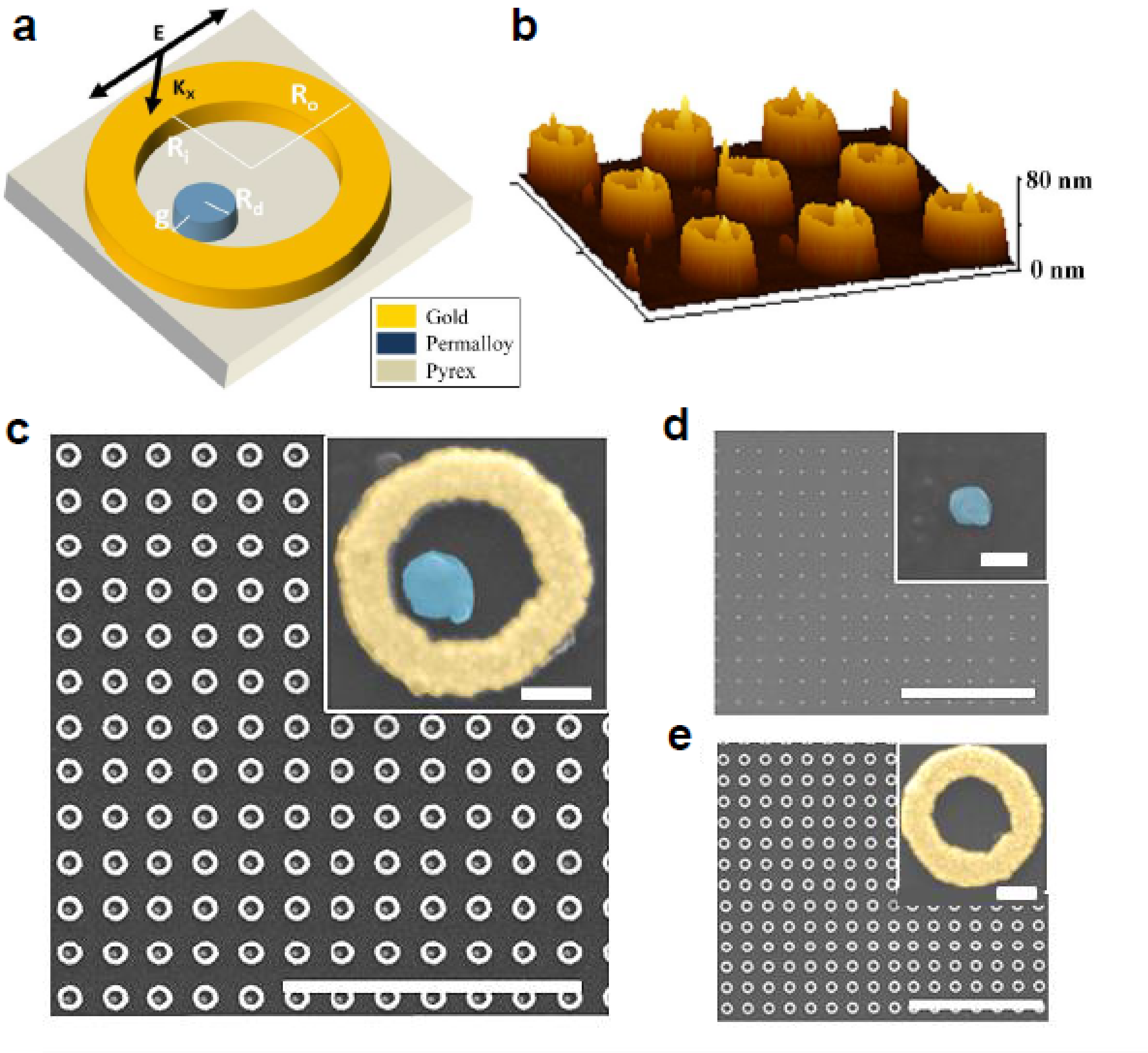
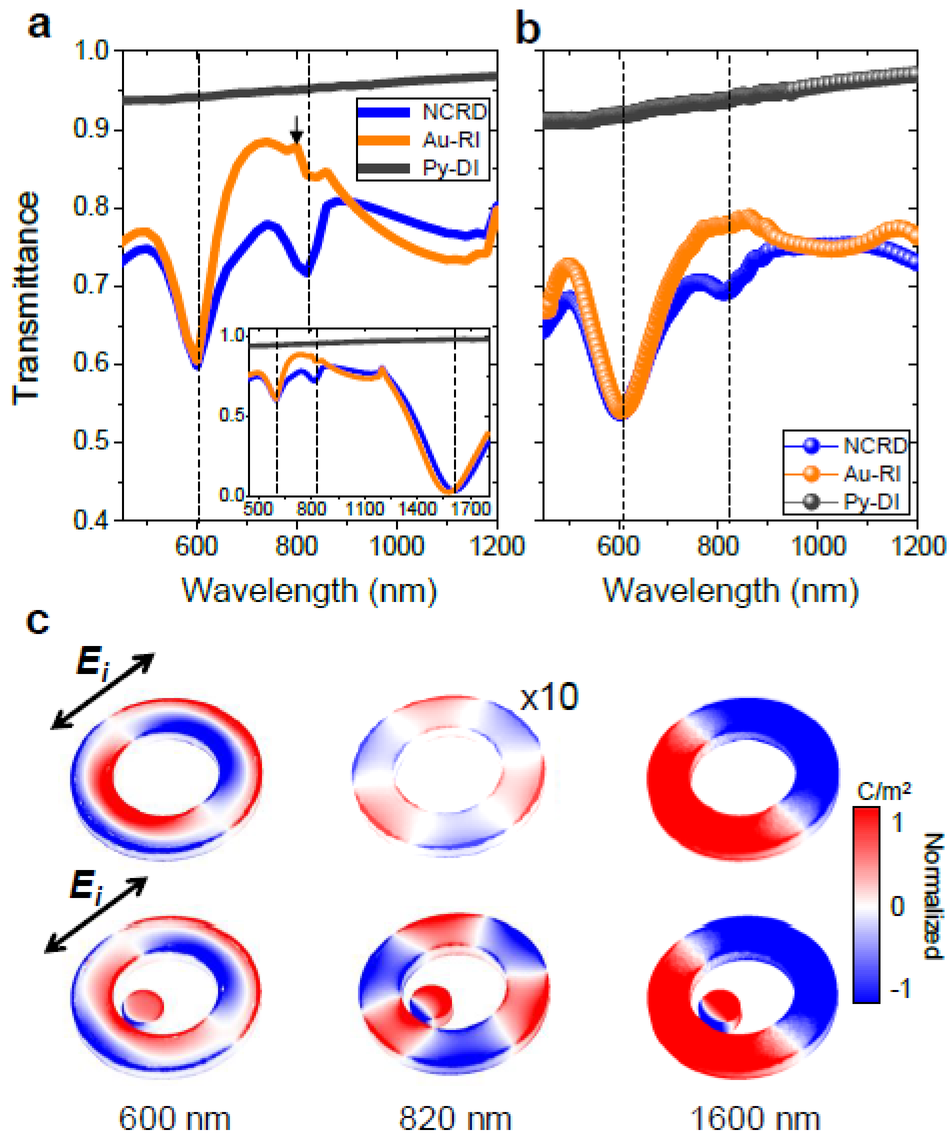
Magnetoplasmonics in nanocavities: Dark plasmons enhance magneto-optics beyond the intrinsic limit of magnetoplasmonic nanoantennas

Enhancing magneto-optical effects is crucial for size reduction of key photonic devices based on non-reciprocal propagation of light and to enable active nanophotonics. We disclose a so far unexplored approach that exploits dark plasmons to produce an unprecedented amplification of magneto-optical activity. We designed and fabricated non-concentric magnetoplasmonic-disk/plasmonic-ring-resonator nanocavities supporting multipolar dark modes. The broken geometrical symmetry of the design enables coupling with free-space light and hybridization of dark modes of the ring nanoresonator with the dipolar localized plasmon resonance of the magnetoplasmonic disk. Such hybridization generates a multipolar resonance that amplifies the magneto-optical response of the nanocavity by ~1-order of magnitude with respect to the maximum enhancement achievable by localized plasmons in bare magnetoplasmonic nanoantennas. This large amplification results from the peculiar and enhanced electrodynamic response of the nanocavity, yielding an intense magnetically-activated radiant magneto-optical dipole driven by the low-radiant multipolar resonance. The concept proposed is general and, therefore, our results open a new path that can revitalize research and applications of magnetoplasmonics to active nanophotonics and flat optics.



Magnetoplasmonic NCRD ferromagnetic-nanoantenna/gold-nanocavity and parent Py-DI and Au-RI nanostructures. a Schematic of the NCRD hybrid structure with its four geometric characteristic parameters. b Atomic force and c SEM images of the individual NCRD nanocavity and array. SEM images of the parent single d Py-DI, e Au-RI constituents and arrays. The scale bars in panels c-e correspond to 5 µm and those in their insets to 100 nm.

Both experimental and simulated spectra of the NCRD array display two strongly marked dips located at 600 and 1650 nm and a weaker dip at 820 nm. A comparison with the spectra (simulated and experimental) of the array of bare Au-RI and a close inspection of the spectral dependence of calculated surface charge distribution maps in Fig. 2c, reveal that the two most prominent dips in the NCRD correspond to the excitation of the so-called antibonding and bonding plasmonic resonances in the Au ring portion of the nanocavity at 600 nm and 1650, respectively.



Au-RI and NCRD optical properties and electrodynamics. a Simulated and b experimental transmittance spectra for the NCRD, Py-DI and Au-RI structures. Dashed lines mark the major features in the spectra at 600, 820 and 1600 nm. The small black arrow in panel a highlights a minor feature due to the weak far-field diffractive coupling in a simulated periodic array of defect-less structures. c Surface charge density maps (see Methods) for the Au-RI and NCRD structures at 600, 820 and 1600 nm, normalized to the map at 820 nm for the NCRD for direct comparison. Simulations in panel c are carried out using linearly polarized electromagnetic radiation as indicated by the black arrow (Ei = 1V/m). The surface charge density for the Au-RI at 820 nm has been multiplied by a factor 10 for visualization purposes.

We have demonstrated that high-order multi-polar dark plasmon resonances in magnetoplasmonic nanocavities can be utilized to achieve unprecedented enhancement of the magneto-activated optical response, beyond the present limitations of magnetoplasmonic nanoantennas, enabling a far more efficient active control of the light polarization under weak magnetic fields. The superior behavior of geometrical symmetry broken magnetoplasmonic nanocavities, as compared to corresponding nanoantennas, is explained by the generation of largely enhanced magnetic-field-induced radiant dipole in the magnetoplasmonic nanoantenna driven by a hybrid low-radiant multipolar Fano resonance mode. Therefore, in this novel design, a large enhancement of the magneto-optical response, i.e., the magneto-activated electrical dipole inducing the light polarization modification, is achieved without a significant increase of the pure optical response thanks to the low-radiant character of the hybrid mode. As a result, in the NCRD magnetoplasmonic nanocavity the MOA is additionally amplified by ~1-order of magnitude with respect to the parent Py-DI structure. The novel concept unveiled here opens a fresh path towards applications of magnetoplasmonics to a variety of fields ranging from flat and active nanophotonics to sensing. Therefore, this exploratory work should catalyze future research. Tuning of dark and bright plasmon modes can be achieved by varying the design and the materials to boost both plasmonics (e.g. using silver instead of gold) and intrinsic MO activity (e.g., employing multilayers Au/Co), as well as tuning the relative spectral position and sharpness of the dark and dipolar modes, and thus of the Fano resonance line shape and intensity. Finally, this mechanism might have a huge impact on forthcoming photonic nanotechnologies based on plasmon-mediated local enhanced manipulation of electronic spin-currents opening excellent perspectives in disclosing novel opto-electronic phenomena.

For more information: https://arxiv.org/abs/1903.08392v1