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Simulation, Fabrication and Observation of Plasmonic Halos

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Abstract

We present the discovery and systematic study of a novel optical phenomenon, wherein optically-pumped surface plasmon polaritons (SPP) on circular silver microcavities form confined drumhead modes that, under off-resonant conditions, transform to colorful far field radiation at their circumferential boundaries [1], as shown in Figure 1. We call this phenomenon the plasmonic halo." Simulations of the surface plasmon drumhead modes are carried out in the RF Module of COMSOL Multiphysics®. Figure 2 shows cross-section views of electric field profiles under x polarized bottom illumination. When a resonance condition is met (e.g., 512.5 nm), the vertical SPP component Ez will be maximized, as shown in Figure 2a. Correspondingly, the far-field component Ex will be minimized as the result of the out-of-phase interference between the SPP originated and directly transmitted photons (Figure 2b). However, when the resonance condition is not satisfied (e.g., 491.5 nm), the SPP energy (and thus the SPP-originated photon flux) is reduced, increasing the out-coupled light intensity, as shown in Figure 2c and d. Near-field measurement of the surface plasmon drumhead modes are carried out in the Nanonics MultiView 4000 NSOM system. The measured field profile agrees well with the simulated one, as shown in Figure 3. We also identified various drumhead modes via investigation of the far field transmission spectrum data through the halo structures. We have thus demonstrated both experimentally and theoretically that such circular microcavities integrated with perimeter step gaps can generate surface plasmon cavity modes, and modulate optical transmission/emission through/from the device, yielding the plasmonic halo effect. Via the tuning of geometric and/or material parameters, optical properties of this device can be manipulated in the visible range, leading to promising applications in biomedical plasmonics, dielectric constant sensing and discrete optical filtering, among others.

Reference

1. Fan Ye et al., “Plasmonic Halos -- Optical Surface Plasmon Drumhead Modes.” Nano Letters, 13, 519-523 (2013)

Figures used in the abstract

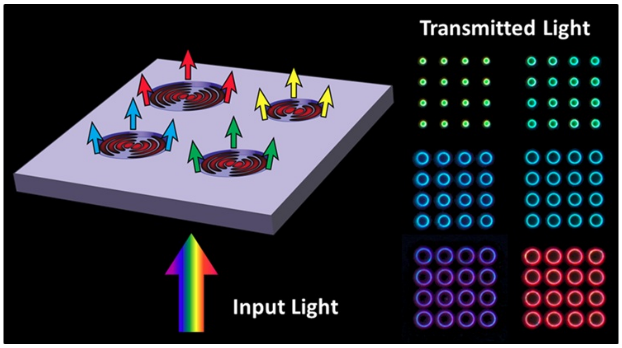

Figure 1: Figure 1. (left) Schematic cartoons showing light shining on, forming surface plasmon drumhead modes, and transmitting through arrays of plasmonic halo structures. (right) Transmission optical microscope images of plasmonic halos with different geometries under white light illumination.

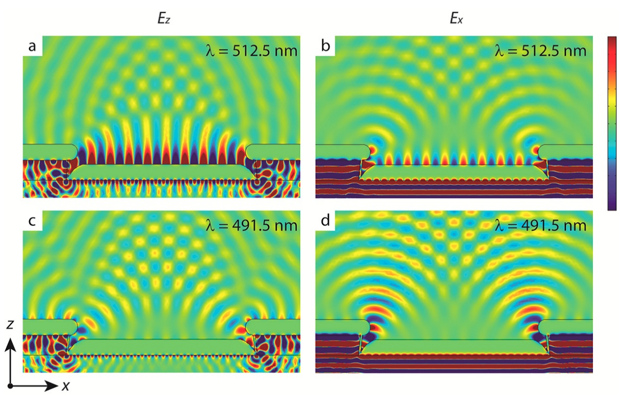

Figure 2: Figure 2. Cross-section views of electric field profiles under x-polarized bottom illumination. (a) Ez profile at resonance (512.5 nm) shows a strong SPP standing wave (cavity mode). (b) Ex at the same wavelength shows weak far-field coupling. (c) Ez profile off resonance (491.5 nm) shows no SPP cavity mode. (d) Ex profile at the same condition shows strong far-field coupling. All four profile maps are on the same linear color scale, from –0.25 to 0.25 V/m, as shown at right.

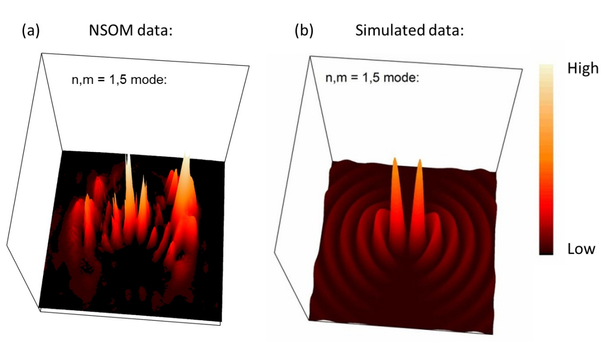

Figure 3: Figure 3. (a) 3 dimensional plot of electric field intensity profile inside a circular plasmonic halo cavity obtained by near-field scanning optical microscopy. (b) 3 dimensional plot of simulated electric field intensity profile within a bounded circular cavity, with light color meaning high and dark color meaning low intensities.