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Abstract – **We demonstrate directional launching of surface plasmon polaritons on thin gold film with a single silicon nanosphere. The directivity pattern of the excited surface waves exhibits rapid switching from forward to backward excitation, which is driven by the mutual interference of magnetic and electric dipole moments supported by the dielectric nanoantenna.**

I. Introduction

High refractive index dielectric nanoparticles are attracting significant attention due to their unique properties due to inherently strong magnetic and electric dipole responses in the visible spectral range[1, 2]. The interplay of these resonances in combination with inherently low level of losses has already inspired all-dielectric-based solutions for superdirective nanoantennas, sensors, metasurfaces for efficient wavefront control and beam shaping, metadevices granting giant enhancement of non-linear effects, etc.

Yet another possible application of subwavelength particles is for launching surface waves, in particular, surface plasmon polaritons (SPP). Recently, directional launching of SPP was demonstrated with magnetic nanoantennas[3] and 1D grooves[4]. Dielectric nanoparticles, by merit of possessing both magnetic and electric polarizabilities, could provide additional tools [5] for controlling the directivity of surface waves in the visible and infrared spectral ranges. In this work, we reveal unique opportunities for manipulation of directivity pattern of SPP delivered by mutual interference of electric and magnetic dipole resonances of single dielectric nanoparticle. We demonstrate switching between directional excitation of SPP on gold substrate along the wavevector of the incident beam to total suppression of forward scattering followed by restoration of forward SPP scattering pattern at longer wavelengths.

II. Surface plasmon polaritons from silicon nanosphere

To study the patterns of launching of surface plasmon polaritons (SPP) by a silicon nanosphere, we employ analytical model based on Green's function approach[6]. This model relies on calculation of the sphere electric and magnetic polarizabilities in dipole approximation. While for s-polarized excitation the SPP directivity pattern is inherently symmetric, p-polarized excitation can provide directional excitation of SPP due to interference effects between the induced dipole moments. In the case of p-polarized pump, three independent dipole moments that contribute to SPP waves are excited in the silicon nanosphere: magnetic dipole along the y axis, characterized by the magnetic polarizability m_y and two electric dipoles along z and x axes with polarizabilities p_z and p_x, respectively (see Fig. 1a).

The sphere polarizabilities are calculated via Green's function approach with account for the influence of the substrate[6, 7], after which the fields of SPP excited by the induced dipole moments are obtained in a straightforward manner. The calculated maps of forward and backward directivity of SPP from 275 nm silicon nanosphere are shown in Fig. 1b,c. The maps demonstrate resonant switching between forward and backward SPP excitation at 870 nm, with forward directivity reaching zero near the angle of incidence of approximately 30 degrees.

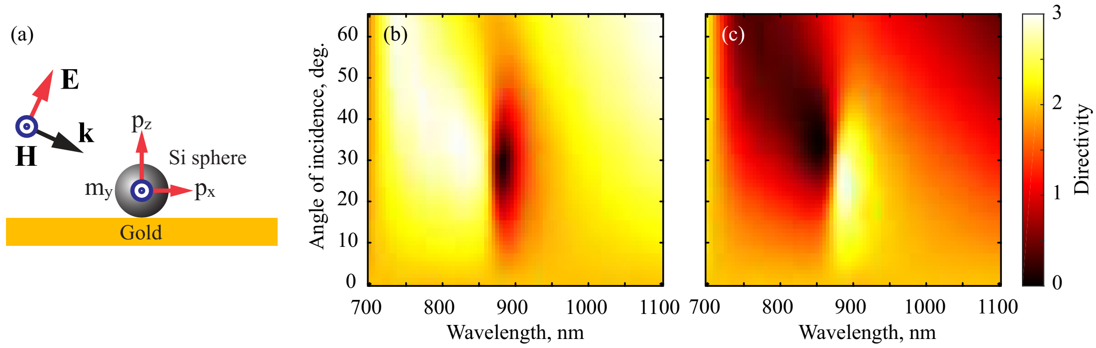

Fig. 1: Analytically calculated maps of (a) forward and (b) backward directivity of surface plasmon polariton launched by a single 275 nm silicon nanosphere on gold substrate. The SPP direction is defined with respect to the direction of the in-plane component of the wavevector of the incident plane wave.

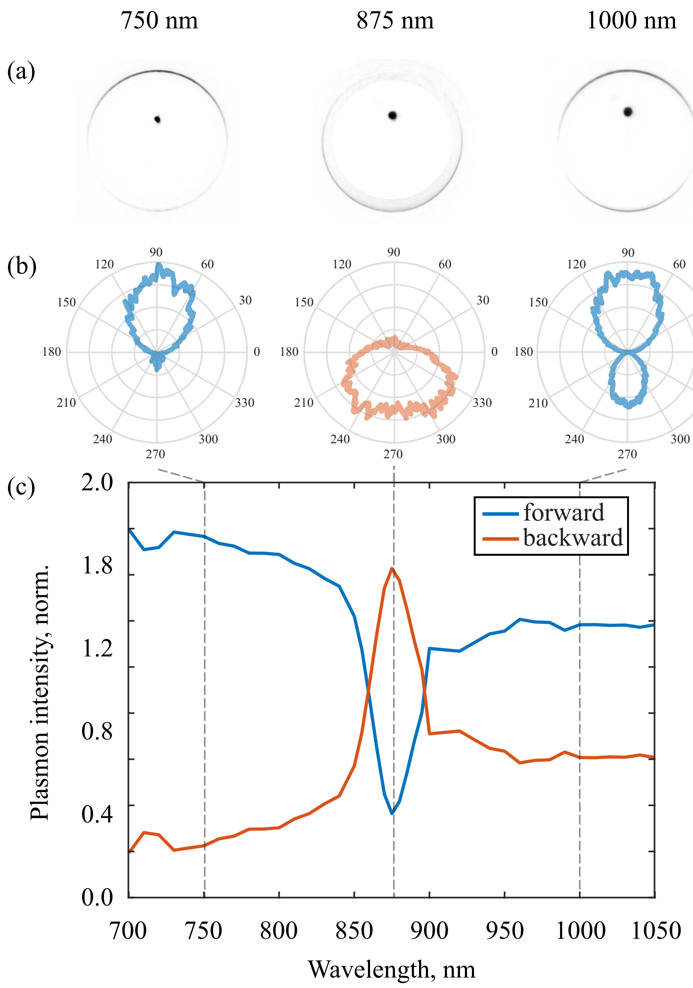

Fig. 2: (a) (False color) Fourier plane images of SPP excited by a 275 nm silicon nanosphere on 40 nm gold layer at 750, 875 and 1000 nm wavelengths. (b) SPP directivity patterns reconstructed from the measured Fourier images. (c) Spectral dependence of forward and backward SPP intensity demonstrating fast switching between SPP excitation directions. The wavelengths corresponding to data presented in (a,b) are marked with dashed lines.

III. Leakage radiation microscopy experiments

To demonstrate the effect of SPP directivity switching experimentally, we realized the setup for leakage radiation microscopy combined with Fourier plane imaging optics [8]. A series of silicon nanospheres with a diameters ranging from 240 to 300 nm obtained with fs laser ablation was transferred to 40 nm gold layer on glass substrate via nanomanipulations under electron beam. SPP was launched from the sphere by exciting it with a TM-polarized beam incident at ≈30 degrees to the substrate normal and mildly focused with a achromatic doublet lens. The SPP radiation leaking through thin gold film was collected from the bottom with an oil immersion objective (Zeiss 100x, NA=1.46). In the Fourier imaging optical channel, the incident beam was filtered with a beamstop to avoid camera overexposure.

Figure 2a and b show the Fourier plane images and directivity patterns of SPP from 275 nm nanosphere for three distinctively different regimes at three wavelengths: highly directional forward excitation (750 nm), inversion of the directivity pattern at 875 nm, and recovery of forward excitation regime at 1000 nm. The resonant behavior of the switching process predicted by the analytical model is best illustrated in Fig. 2c, where the spectral dependence of SPP leakage radiation intensity in forward and backward half-planes is shown. The backward SPP excitation regime manifests itself only within an extremely narrow band of about 30 nm.

IV. Conclusion

In summary, we have revealed fascinating modifications of directivity pattern of surface plasmon polaritons excited by a single high-index dielectric nanoparticle. We showed that for particular angle of incidence, mutual interference of electric and magnetic dipole moments of the nanoparticle provides total suppression of the surface wave launched in either forward or backward direction. The experimental demonstration of rapid switching between these regimes was carried out via leakage radiation microscopy combined with Fourier plane imaging optics, which allowed to reconstruct full spectral dependence of the SPP directivity pattern. The results could find application for designing highly efficient nanoantennas for controlling the propagation of surface waves.

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