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Eccentric metallo-dielectric core-shell nanoparticles for light guiding and switching

High Refractive Index Dielectric (HRID) nanoparticles (NPs) have been proposed as an alternative to metallic ones due to their low absorption and magnetodielectric response in the VIS and NIR ranges. Important scattering directionality (SD) effects can be obtained and systems constituted by dimers of HRID NPs present switching effects by playing with the polarization, frequency or intensity of the incident radiation.

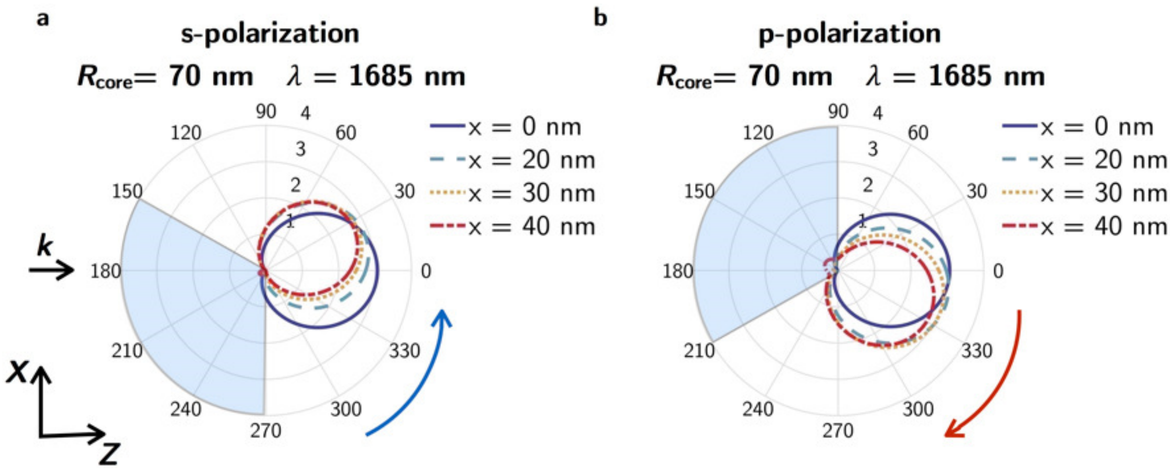

Fig. 1. Scattered intensity by an eccentric core-shell (Rcore=70 nm and Rext=230 nm) spherical nanoparticle when its core is displaced along the X-direction. The incident beam (k) propagates along the Z-axis with polarization (a) perpendicular (s-polarization) and (b) parallel (p-polarization) to the scattering plane. The illuminating wavelength is λ = 1685 nm (This corresponds to the Zero-Backward condition). The blue and red arrows refer to the rotation direction.

In this work, we show that SD effects can be achieved with a single eccentric metallo-HRID core-shell nanoparticle, in particular a Ag-Si core-shell nanoparticle, when its metallic core is shifted from its center. Depending on this shift, these scattering units show different directionality behaviors: 1) If the core's shift is parallel to the propagation direction of the incident radiation, SD conditions can be enhanced. 2) If it is perpendicular to the direction of the incoming beam, those scattering units can operate as switching devices. In fact, we report a rotation of the main scattering lobe either clockwise or counterclockwise depending on the polarization of the incident radiation. This suggests that this sort of eccentric core-shell NPs show efficient configurations for redirecting the incident radiation to certain directions respect to that of forward and backward. This behavior can be exploited for building operational switching devices, whose "on"/"off" states only depend on the polarization of the incoming wave. The analysis of the scattered radiation has been performed at 90º with respect to the incident radiation. This configuration avoids any parasitic effect due to the incident beam. Figure 1 shows the scattering diagrams for an isolated eccentric metallo-dielectric core-shell nanoparticle of radius R_{ext} = 230 nm, whose core (R_{core} = 70nm) has been shifted along the *X*-axis (perpendicular to the incident wave direction. See the rest of details in the figure caption). By swapping the polarization of the incident radiation from s (perpendicular to the scattering plane, *ZX*) to p (parallel to the scattering plane) and fixing a minimum intensity threshold (which will be considered as the "off" state of the device), the intensity of the scattered radiation at 90° goes from a “high” (“on” state) to a “low” (“off” state) level.

We also obtain both cumulative radiation guiding effects, by using chains of these scattering units, and, in the case of 1D periodic arrays, redirection of diffracted intensity as a consequence of “induced” blazing effects. Figure 2 (a) and (b) show near and far field performances of a chain of 6 of the proposed scattering units. This evidences the enormous potential of the directionality properties of these nanostructures, paving the way for new nanoantenna designs. Figure 2 (c) shows the scattering patterns of a system built with 5 core-shell NPs, either concentric or eccentric, distributed as a 1D array (see figure caption for details). A redirection of the diffracted intensity, due to the “induced” geometrical anisotropy of the isolated NP, can be observed.

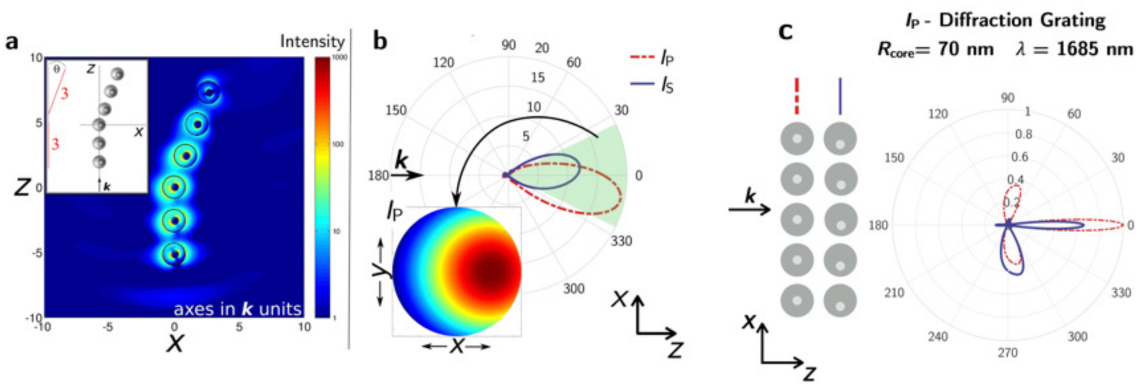

Fig. 2. (a) Near field map of a V-shaped chain of 6 eccentric core-shell NPs with radii Rcore=70 nm and Rext=230 nm with a core displacement of 30 nm in the x-direction and illuminated with a beam propagating in Z and polarized along the X-axis. The angle between the two segments of particles is θ = 20º. The distance between the particles along the x-axis is 137 nm. The plot corresponds to the ZX plane for the wavelength where the Zero-Backward condition holds for the isolated particle. (b) Scattering diagram of the V-shaped chain when illuminated at the Zero-Backward condition with a p- (red dashed-dotted line) and s-incident polarization (blue solid line). The inset shows far-field observation of the normalized total scattered intensity, within a solid angle of 30°, for p-polarized incident radiation. (c) Scattered intensity by a 1D periodic array of five concentric (red dashed line) and eccentric (blue solid line) core-shell nanoparticles (Rcore=70 nm and Rext=230 nm). In the case of the eccentric core-shell, the core has been shifted 30 nm along the polarization direction (X-axis). The period of the array is 1711 nm and it is illuminated by a p-polarized plane wave with λ = 1685 nm that propagates (k) in the Z-direction. The numerical data are normalized to the maximum intensity scattered by the 1D periodic array structure made of concentric spheres.

The scattering units proposed in this research, constitute possible new building-blocks for more complex systems for applications in optical communications, solar energy harvesting and light guiding at the nanoscale level.

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