High Performance Nanosensors Based on Plasmonic Fano-Like Interference

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Abstract

Unlike those propagating at metal/dielectric interfaces, localized collective oscillations of charges confined to the surface of metal nanoparticles can be directly excited by external illumination without the need of any additional coupling-in technique, provided that particles are much smaller than the incident wavelength. These oscillations, which can be pictured as a "wave" of electrons moving across the surface of the particle, are referred to as localized surface plasmon resonances (LSPRs) and they are responsible of nanoparticles' bright colors when in colloidal suspension, as a result of their intense absorbing and scattering of light in the visible range.

One of the most appealing properties of LSPRs is that their resonant frequency strongly depends on nanoparticles's size, shape and composition, as well as on the refractive index of the surrounding medium. Given that present technological advances allows one to control particle geometry down to nanometer scale, spectral shift of LSPRs can then be used to detect extremely small changes of the immediate dielectric environment. For instance, such as those produced by the binding of some biological molecules with a higher refractive index than that of their aqueous solvent.

When assessing the actual performance of a refractive index sensing scheme based on the spectral shift of a given plasmon resonance, we have to first consider its refractive index sensitivity, which is defined as the linear regression slope within a given range for the position of the resonance (either a peak or a dip) as a function of refractive index. This magnitude is usually expressed in terms of wavelength or energy shifts per refractive index unit and it provides a preliminary measure of the sensor quality. However, sensitivity alone cannot characterize the sensor performance but in an ideal scenario of infinitely high spectral resolution and no system noise. Sherry et al. [1] therefore proposed the so-called figure of merit (FoM), which is defined as the plasmon resonance sensitivity divided by its "Full Width at Half Maximum" (FWHM), as the most meaningful indicator for evaluating the performance of LSPR-based sensors. Such dimensionless quantity allows one to directly compare the sensing properties of different systems irrespective of their shape, size and operating wavelength.

According to its very definition, the optimal FoM would then be obtained from those resonances exhibiting both high sensitivity to environment and narrow FWHM, which are precisely the main features of spectral line profiles arising from Fano interference [2]. Such an interaction of discrete- and continuum-like states (often labeled as "dark" and "bright" modes) has already been employed for refractive index sensing by means of either propagating or localized plasmon resonances.

In order to design high performance LSPR-based nanosensors, we have focused our attention to the occurrence of asymmetric line shapes in the scattering spectra of single metallic nanorods acting as half-wave antennas in the optical range. Contrary to the common assumption that interference does not play a role in the total scattering or extinction of a single metallic surface, we have found [3] that longitudinal plasmon resonances occurring at individual metallic nanoparticles may present Fano-like interaction provided that they overlap in both spatial and frequency domains. Next, we propose [4] two different configurations for which this Fano-like interference can be easily employed in refractive index sensing: a colloidal suspension of nanospheroids (nanorice) and a single nanowire with rectangular cross section (nanobelt) on top of a dielectric substrate. We numerically study the performance of the two in terms of their figures of merit, which are calculated under realistic conditions. For the case of nanorice, we explicitly incorporate the effect of size dispersity into the simulations. Our obtained results show that the application of the proposed configurations seems to be not only feasible but also very promising.

References

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Figure 1: Schematic representation of the emergence of asymmetry in the spectral response of different rod-shaped nanoantennas.

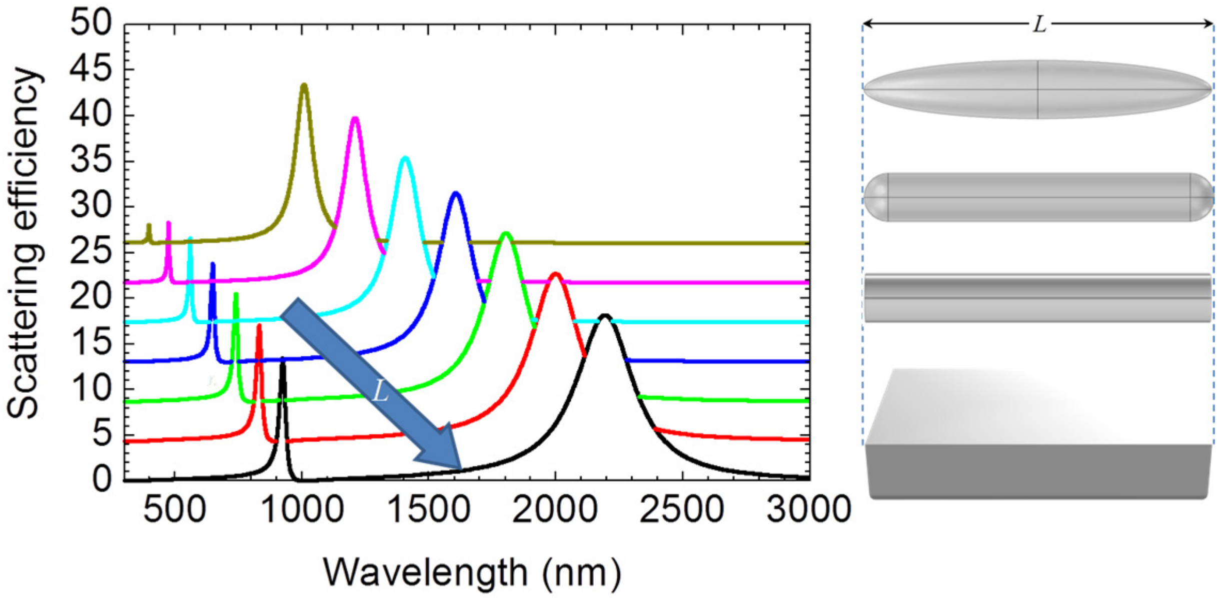

Figure 2: Schematic representation of our two proposed configurations for refractive index sensing based on plasmonic Fano-like interference.