Higher-order resonances in single-arm nanoantennas: Evidence of Fano-like interference

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Experimental and theoretical investigations have shown that metallic nanorods act as standing-wave resonators for localized plasmon resonances in the optical regime [1,2], thus exhibiting geometrical half-wavelength resonances with spectral positions depending mainly on the length of the rods. This particular type of so-called "optical nanoantennas" have raised the prospect of significant improvements in fields such as photodetection [3], field-enhanced spectroscopy [2,4], or control of emission direction in single-molecule light sources [5].

Generally speaking, most of device-oriented studies are focused on nanoantennas operating at the dipole-like resonance. However, structures with a high aspect ratio may support additional resonances that have usually been the subject of a more fundamental research work. Hence, several authors have already elucidated the scaling properties of high-order longitudinal modes, as well as their dependence on shape, size, orientation and dielectric environment by means of diverse approaches and techniques. Nevertheless, a relevant issue has yet to be addressed for multi-resonant nanoantennas, that is the emergence of asymmetric, line profiles in single particle extinction or scattering spectra. Interestingly, such a feature seems to go unnoticed for the nanoplasmonics community, despite being apparent in some previous reports.

In this work [6], we show that these asymmetric line profiles can be easily understood in terms of the so-called Fano-like interference between localized plasmon resonances that has been recently reported for a variety of coupled metal nanoparticles [7,8]. Being more precise, we present a simplified analytical model that describes spectral features of a single-arm nanoantenna in terms of Fano-like interference. Contrary to the common assumption that interference does not play any role in total scattering or extinction of a single metallic surface, we find a good agreement with numerical results, which are attained through the separation of variables (SVM) [9], finite element (FEM) [10], and surface integral equation (SIEM) methods [11,12].

In Figure 1 we present the calculated scattering efficiency Q_{sca} for a single silver spheroid surrounded by glass (ε_d= 2.25) under the assumption that incident field is p-polarized and impinges perpendicular to the long side of the rod. Different curves correspond to increasing values of total length *L* within the [100,400] nm range, whereas the polar diameter *D* is set to 30 nm for all calculations. As can be seen, the position of resonances increases linearly within the *L* range. For *L/D*>5, the peaks arising from resonances with n=1 and n=3 are clearly apparent, as it is the asymmetry of the line shape between them. This suggests the interaction of adjacent resonances to be compatible with a Fano-like interference model [6], where the lower resonance plays the role of continuum in canonical Fano line shape [7].

This is in turn numerically revealed for a variety of single-arm nanoantennas, namely:

- Nanospheroids,
- Nanorods,
- Nanowires.

Furthermore, we make use of explicit analytical expressions for light scattering by spheroids to conclude that not only spectral but also spatial overlap (i.e. non-orthogonality) between interacting modes underlies the emergence of such single-rod resonances [6].

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Figures

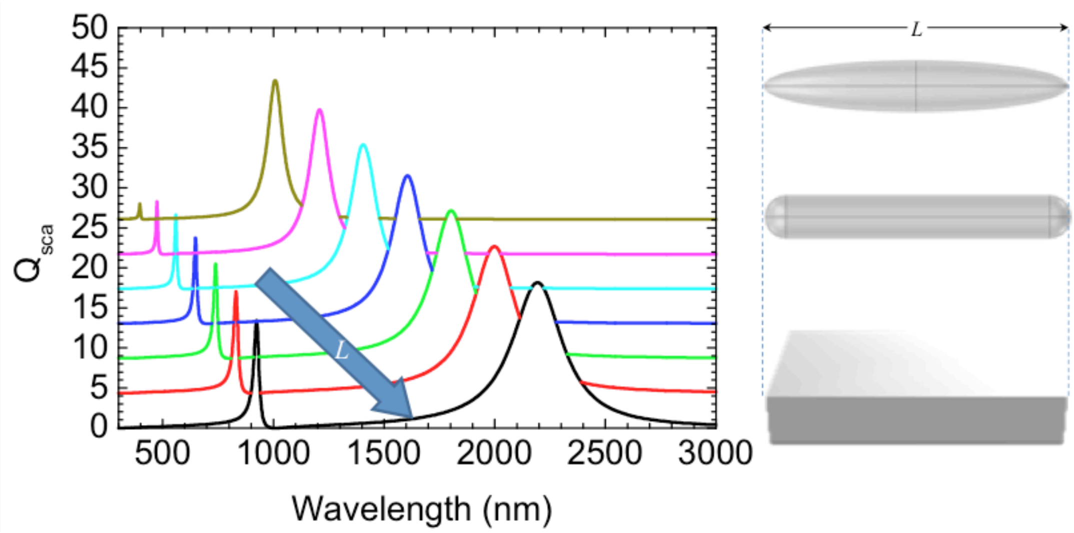

Figure 1: Calculated scattering efficiency as a function of wavelength for a single Ag spheroid (top right) surrounded by glass (ε_d = 2:25). Incident field is p-polarized and impinges perpendicular to the rotation axis of the spheroid. Different curves correspond to increasing values of *L*, whereas *D* is set to 30 nm for all calculations. Right: Nanorod geometries for which evidence is found of Fano-like interference [6].