Theory of Fano-like resonances in sub-wavelength plasmonic nanostructures

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Asymmetric scattering profiles have been recently observed in metal nanostructures excited by an electromagnetic field at optical frequencies, including dolmen-type arrangement, ring-disk systems, nano-shells, hetero-dimers, and artificial plasmonic molecules [1-2]. Fano-like resonances in metal nanostructures have generated large interest, particularly in relation to optical sensors which, taking advantage of the sharp resonant line-shape, could potentially offer a significant improvement in sensitivity.

Although extensive experimental and numerical studies of subwavelength complex metal structures have been performed, only few attempts have been done to theoretically describe such resonances [3-5]. Currently, Fano-like resonances are found experimentally or numerically by probing plasmonic nanostructures of complex shapes with radiation of various frequencies and by identifying asymmetric profiles in their scattering spectra. It is therefore highly desirable to develop a rigorous technique for the direct calculation of the frequencies of electromagnetic radiation for which such resonances occur.

In the present work, we derive the theory of coupled plasmon modes in subwavelength plasmonic structures, valid beyond the Rayleigh limit. Our approach is rooted in the boundary eigenvalue problem for the plasmon resonances and its first and second order radiative-corrections [6]. The problem is tackled in two-steps. First in the small particle regime, we expand the dipole moment of the plasmonic structure in terms of the plasmon modes of the system, and we study the poles and the zeros of the resulting rational function [7]. Next, for particles of size comparable to the incident wavelength we calculate the radiation correction of the position of the zeros of the dipole moment by using the perturbation theory.

Thus, we demonstrate how the coupling between at least two bright modes gives rise to Fano-like resonances in the scattering spectrum and to the plasmon equivalent of electromagnetically induced transparency at the Drude damping limit. Moreover, we provide rigorous conditions in which Fano-like resonances are allowed, a method for the direct calculation of their spectral position and asymmetry degree, and we investigate the dissipation in proximity of a Fano-like resonance.

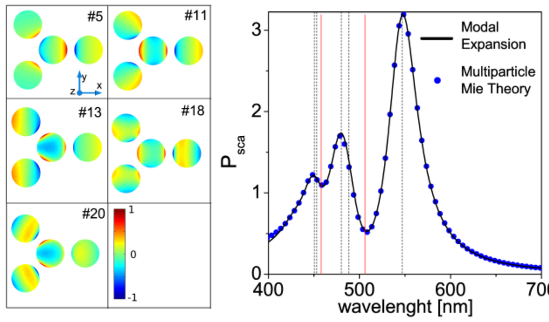

Fig 1. (a) Surface charge density of the bright and excitable eigenmodes of the plasmonic oligomer. (b) Power scattered by the plasmonic oligomer calculated with the modal approach and with the multiparticle Mie theory. The positions of the poles and the zeros are shown with vertical black and red lines, respectively.

Finally, we apply our theory to investigate the Fano-like response of two canonical plasmonic systems: the plasmonic oligomer and the plasmonic dolmen.

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