Plasmon Optical Nanoantennas: Characterization, Design, and Applications in Nanophotonics

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Complex metal nanostructures exhibit plasmon resonances that play a crucial role in various electromagnetic processes stemming from spontaneous emission occurring nearby [1-4]. In this regard, it is crucial first to characterize the localized plasmon resonances for a variety of metal nanoparticles. On the basis of a 2D surface integral equations in parametric coordinates [5], we have indeed calculated the scattering cross sections for nanowires of various shapes (circle, triangles, rectangles, and stars), either isolated or interacting, including near-field intensity maps (with corresponding enhancement factors) and surface charge distributions [4-6]. Good agreement with experimental results for the dimer nanoantennas used in enhanced fluorescence is in turn achieved [6]. In the case of metal nanoparticles resembling a star/flower, which have also been obtained experimentally, large enhancement factors are shown to occur (see Fig.1), making them specially suitable as SERS (surface-enhanced raman scattering) substrates [4].

In addition, we have developed theoretically and numerically a rigorous method to investigate the electromagnetic wave scattering from 3D objects with arbitrary surfaces and dielectric function [7]. The formulation is based on the surface integral equations for the electric and magnetic fields given by the Stratton-Chu formulas. The integral equations are generalized for a 3D object with its surface in parametric coordinates (recently derived for 2D objects in Ref. [5]). This formalism straightforwardly allows one to deal with an arbitrary number of scatterers and shapes, with the advantage that it scales with the scatterer surface (rather than its volume).

With regard to nanoantenna-enhanced photonics, single molecule fluorescence close to metallic nanoantennas has been thoroughly explored by calculating radiative and nonradiative decay rates (and quantum yields), addressing crucial issues as the modification and enhancement (or quenching) of spontaneous emission in (bio)molecular and optoelectronic systems, due to the strong impact on the local (near-field) electromagnetic density of states of surface-plasmon resonances in dimer nanoantennas [1,3]. The strong coupling of the optical emitter to the nanoantenna is also studied in the resulting near- and far-field patterns, which exhibit significant qualitative and quantitative variations [3]. Experimentally, resonant enhancement of the radiative and nonradiative decay rates of a fluorescent dye is observed for dimers with optically coupled arms with narrow (~20 nm) gaps [1], in agreement with our electrodynamic model calculations [1,3]. On the other hand, metallic nanowire trimers have been theoretically investigated, with associated multiple plasmon resonances that can be exploited to doubly enhanced inelastic and/or nonlinear optical processes [2]; this has straightforward implications for low efficiency emitters in, e.g., (bio)molecular sensing or optoelectronic devices.

The optimal design of nanoantennas with specific properties is, on the other hand, an aspect of the inverse problem that had not received too much attention until recently, despite being crucial from the point of view of applications. In order to find the optimal nanoparticle geometry that maximizes/minimizes a given optical property, we have made use of bio-inpired stochastic technique based on genetic algorithms, which exploits the surface integral equation formulation [5] to solve the direct scattering problem. The performance of this stochastic method is proved by showing how the optimization procedure converges to a nanostar geometry that exhibits a resonance at or near a given wavelength [8]. This method will be exploited to design metal nanoantennas optimizing quantum-dot photoluminescence.

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Figures

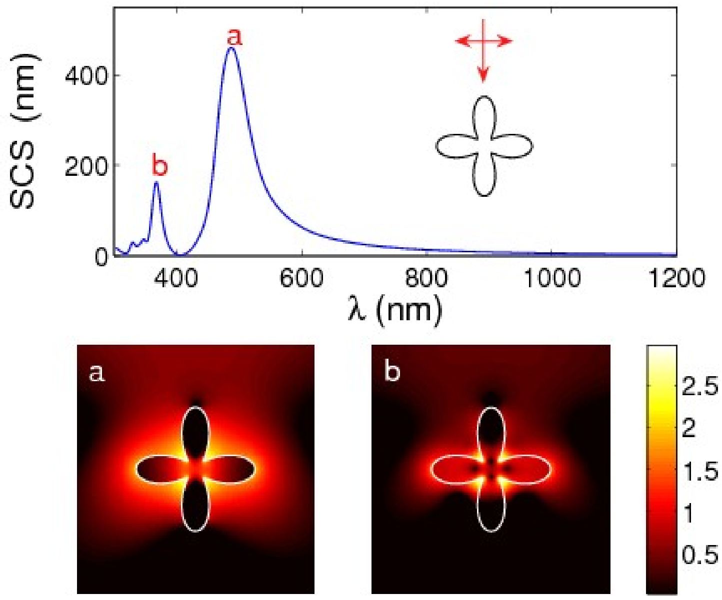

Figure 1: Scattering Cross Section for a Ag four-petal nanoflower with average radius of 30 nm and oscillation amplitude of 20 nm (blue curve). (a,b) Electric-near-field intensity distribution in log scale at both plasmon resonances [7].

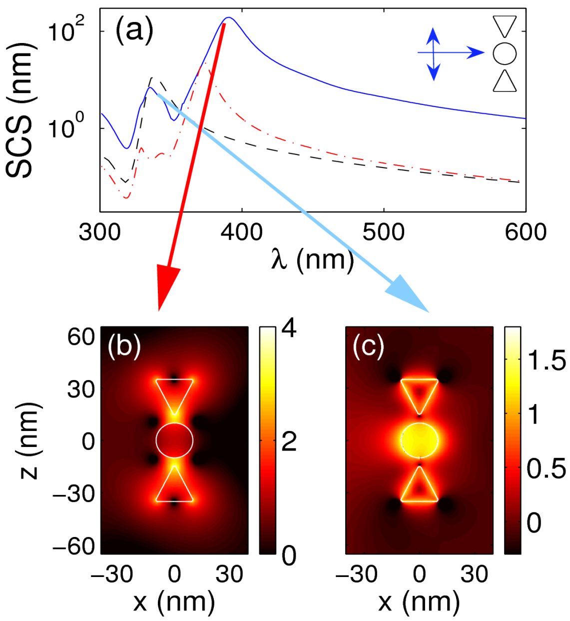

Figure 2: (a) Scattering cross section for a Ag trimer (solid curve) consisting of a cylinder with 20 nm of diameter between two triangles; each triangle has 20 nm of base and 20 nm of height. The distance between each triangle and the cylinder is 5 nm, the electromagnetic field impinging from the left (see inset), p polarization. SCS of a Ag triangular particle (dashed-dotted curve) and of a cylinder (dashed curve). (b), (c) Near electric field intensity in a log10 scale (p polarization) at the plasmonic resonances, normalized to that of the incident field. (b) λ=390 nm, © λ=334 nm [2].