Extreme plasmon resonant field enhancement in multi-material nanoparticle trimers

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Abstract: Field enhancement of few-particle clusters consisting of spherical nanoparticles made from different materials is numerically investigated. Results demonstrate that multiplicative field enhancement can occur in multi-material trimer (Ag-Au-Ag) structures.

OCIS codes: (250.5403) Plasmonics; (260.5740) Resonance; (290.5850) Scattering, particles

Systems supporting coupled plasmon resonances are of great interest in nanophotonics due to their ability to provide stronger field enhancement factors than can be obtained using isolated plasmonic resonators. This allows such systems to improve the sensitivity of surface-enhanced Raman spectroscopy (SERS), improve the performance of certain nonlinear optical processes and enhance spontaneous emission and stimulated emission rates. It has been demonstrated that a specific type of coupled plasmon resonance observed in a self-similar chain of metal nanospheres, can produce even larger field enhancement factors[1]. This phenomenon, sometimes called cascaded plasmon resonance, occurs when near-field coupled systems exhibit the same resonantly frequency while having significantly different polarizability. The effect has been investigated experimentally and theoretically in several studies, with most work focusing on coupled nanospheres made of the same material inspired by the early publications. From theoretical studies it is clear that a large volume ratio between adjacent resonators is required for maximum field enhancement [2]. We recently expanded this work to include shape-tuned particles compatible with electron beam lithography[3].

In this study, we demonstrate a novel approach in which the near-field coupled resonators consist of different materials. We investigate internal and external cascaded field enhancement of multi-material trimer structures consisting of a small gold nanoparticle located between two large silver nanoparticles. Figure 1 shows a schematic of such multi-material trimer structure.

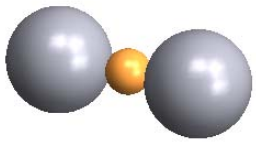

Fig. 1. Schematic of Ag-Au-Ag trimer structure.

In the structure shown in Fig. 1, the large silver nanoparticles in dimer configuration play the role of the optical resonator with large polarizability, while the small Au particle is excited by the enhanced driving field provided by the silver dimer. The polarization-dependent field enhancement and scattering spectra of the trimers were calculated numerically as a function of nanoparticle size and inter-particle spacing. Figure 2(a-c) show the internal field enhancement of silver dimers in the absence of a central Au nanoparticle for Ag nanoparticle diameters 60nm, 80nm and 100nm at a fixed edge-to-edge spacing of 20nm. The spectra reveal a sharp multipolar peak, as well as a broad resonance associated with a dipolar plasmon resonance that redshifts as particle size increases. The dashed lines show the internal field enhancement inside an isolated 10nm gold nanoparticle. Figures 2(d-f) show the internal field enhancement of a 10nm diameter gold nanoparticle that is part of a trimer structure made using the three silver dimers from Figs. (a-c). The largest field enhancement occurs when the plasmon resonance of the isolated gold nanoparticle matches that of the red-shifted gap resonance of the silver dimer, which occurs for a silver particle diameter of 80nm.

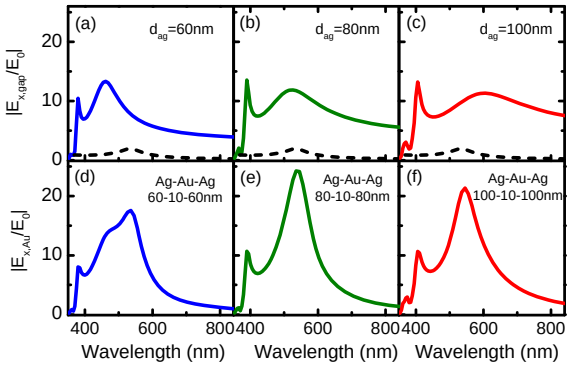

Fig. 2. Field enhancement in the gap of silver dimers at fixed edge-to-edge spacing of 20nm with silver nanoparticle diameter of (a) 60nm, (b) 80nm and (c) 100nm, and internal field enhancement of an isolated 10nm diameter Au nanoparticle (dashed lines). Internal field enhancement of a 10nm gold nanoparticle located at the center of the dimer structures from (a-c).

Figures 3(a-c) show the internal field enhancement in the gap of a silver dimer with a fixed Ag nanoparticle diameter of 100nm for edge-to-edge spacings of 40nm, 30nm and 20nm. Figures 3(d-f) show the internal field enhancement of a 10nm diameter gold nanoparticle placed at the center of the silver dimers from Figs. (a-c). As the multiplied field enhancement is observed for all three edge-to-edge spacings, with the total field enhancement showing characteristics of both the Au resonance (Figs. 2(a-c), dashed lines) and the silver dimer resonance.

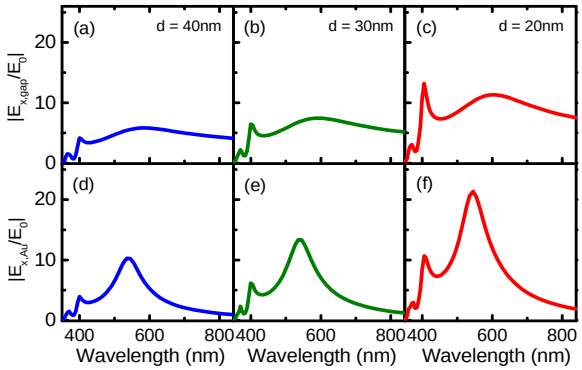

Fig. 3. Field enhancement in the gap of silver dimers for a fixed Ag nanoparticle diameter of 100nm and an edge-to-edge spacing of (a) 40nm, (b) 30nm and (c) 20nm. Internal field enhancement of a 10nm gold nanoparticle located at the center of the dimer structures from (a-c).

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The results in Figs. 2 and 3 show that mutual coupling system in a multi-material trimer enables strong field enhancement inside and around gold nanoparticles. The largest field enhancement occurs when the plasmon resonance wavelength of the silver dimer matches the plasmon resonance wavelength of the gold nanoparticle. The internal field enhancement in the gold nanoparticle exceeds that of isolated Au nanoparticles by up to a factor 15 in the considered Ag-Au-Ag trimer structures, with larger field enhancements expected for smaller inter-particle spacing and larger volume ratio. The presented approach is compatible with chemical synthesis and assembly methods, opening the way to implementation of cascaded multi-material trimers in reliable biochemical sensors that require large electric field enhancement.

[1] Li. K.; Stockman. M. I.; and Bergman. D. J.; "Self-Similar Chain of Metal Nanospheres as an Efficient Nanolens", Phys Rev Lett 91 (22), 227402 (2003).
[2] Toroghi. S.; and Kik. P. G.; "Cascaded plasmon resonant field enhancement in nanoparticle dimers in the point dipole limit", Appl. Phys. Lett. 100, 183105 (2012).
[3] Toroghi. S.; and Kik. P. G.; "Cascaded field enhancement in plasmon resonant dimer nanoantennas compatible with two-dimensional nanofabrication methods", Appl. Phys. Lett. 101, 013116 (2012).