Plasmonics of Nano-Gaps

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Abstract

The field of nano-photonics represents an exciting research area, where optical nanomaterials can slow down, trap and manipulate light at the sub-wavelength scale. Plasmons, i.e. the collective oscillations of electrons in a metallic nano-structure, lead to strong light scattering, absorption and an enhancement of the local electromagnetic field. The unexpected behavior of nano-structured metallic materials, such as the ability to squeeze light into nanometric spaces, has led to a major research area that has the potential to impact across a wide range of photonics products.

In this work, the local electric-field enhancement in a system of dielectric nanoparticles placed very near to a metallic substrate is studied and discussed. Finite-element numerical simulations were used in order to understand the field-enhancement mechanism in this 'dielectric NP-on-mirror' system [1]. To demonstrate the relevance of this study to real-life applications, we show an example of the use of metal-oxide nanoparticles for the direct monitoring of a photo-catalytic decomposition process [2].

A three-dimensional model, using COMSOL Multiphysics® v4.3 (RF Module), was constructed to enable parametric studies. The simulations were performed in two steps: the first step computes the electric field for the substrate only, when illuminated by a plane-wave excitation at the upper boundary. The second step solves for the electric field due to the presence of the nanoparticle on the substrate, using the output from the first step. Perfectly-matched layers (PMLs) were used to absorb the scattered radiation in all directions. In order to reduce the computational time, symmetry planes were used and only one fourth of the model was solved for. A schematic illustration of the two steps of the model can be found in Figure 1.

Under appropriate excitation conditions, the gap between the particle and the substrate becomes a 'hot-spot', i.e. a region of intense electromagnetic field. In Figure 2, the maximum electric field in the gap for various metallic substrates is shown. It can be seen that the peak for each metal is at a different wavelength corresponding to the substrate's surface-plasmon resonance. The spatial field distributions at the peak for a silver substrate are shown in Figure 3.

In this study, it is also shown how the optical properties of a dielectric NP placed on a metallic substrate affects the plasmonic field enhancement in the nano-gap.

Optical COMSOL Multiphysics® simulations have provided valuable information about the near-field enhancement of plasmonic systems. It has been shown that high local electric fields can be generated in small gaps between metallic and non-metallic materials. A dielectric nanoparticle acts as a source of plasmon excitation for an underlying metallic substrate. Dielectric materials with higher optical constants (n,k values) will result in higher near-field enhancements. The advantage of using high refractive-index materials was demonstrated for the case of a metal-oxide nanoparticle above a metallic substrate, which can generate strong surface-enhanced Raman scattering (SERS) signals, and can be used for various applications that are not possible with all-metallic systems.

Reference

1. Tanya Hutter, Fu Min Huang, Stephen R Elliott and Sumeet Mahajan, 'Near-field plasmonics of an individual dielectric nanoparticle above a metallic substrate' The Journal of Physical Chemistry C 117(15) 7784-7790, 2013.

2. Li Li, Tanya Hutter, Alexander S Finnemore, Fu Min Huang, Jeremy J Baumberg, Stephen R Elliott, Ullrich Steiner and Sumeet Mahajan, 'Metal oxide nanoparticle mediated enhanced Raman scattering and its use in direct monitoring of interfacial chemical reactions' Nano letters 12(8) 4242-4246, 2012.

Figures used in the abstract

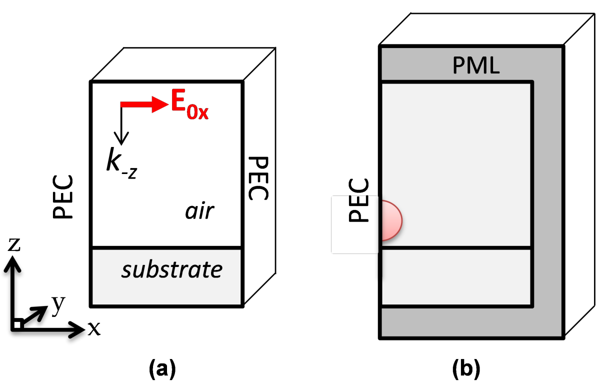

Figure 1: Schematic illustration of the two steps of the COMSOL model.

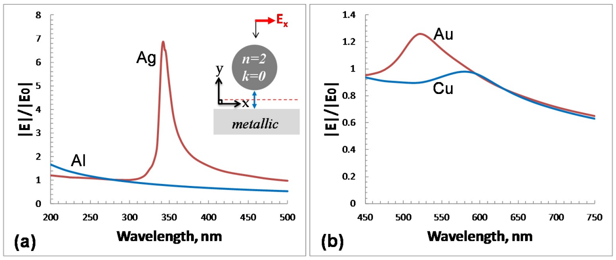

Figure 2: Figure 2: Maximum electric field |E|/|E0| in the gap for a dielectric NP above different metallic substrates: (a) Al and Ag, (b) Au and Cu.

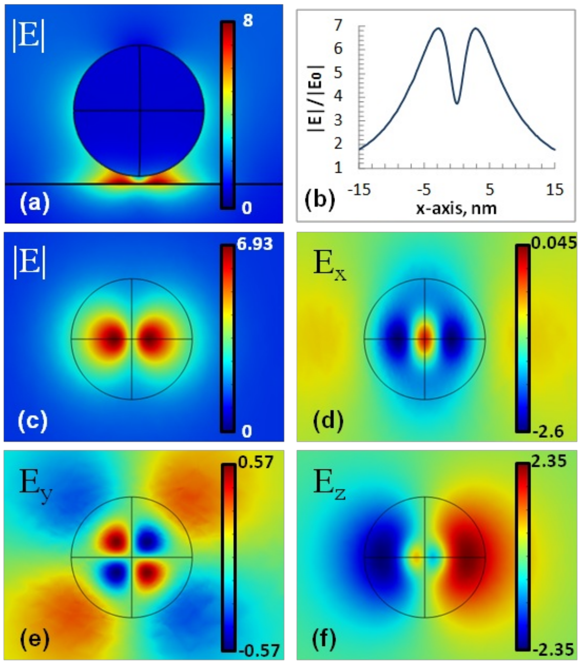

Figure 3: (a) Spatial field distribution |E|/|E0| for a dielectric NP placed above a silver substrate, and (b) the corresponding electric field |E|/|E0| profile along a horizontal line in the middle of the gap. The spatial variation in the middle of the gap of the electric field of (c) |E|/|E0|, (d) Ex/|E0|, (e) Ey/|E0| and (f) Ez/|E0| at 343 nm for a dielectric NP above a silver substrate.