Study of plasmonic oscillations in composite structures through surface integral equation method

D. C. Tzarouchis\(^1\), P. Ylä-Oijala\(^1\), and A. H. Sihvola\(^1\)

\(^1\)Department of Radio Science and Engineering, Aalto University, Finland
dimitrios.tzarouchis@aalto.fi

Abstract — Tailoring the optical response of geometrically complex metal structures and clusters is a highly demanding procedure. In the present work, we demonstrate the usage of the surface integral equation method, for the evaluation of the near fields on metallic scatterers, at the optical regime. In that way, some important physical insights occur, enabling the deduction of useful design guidelines.

During the past decades, electromagnetic scattering theory has been extensively used for the evaluation of the optical response and behavior of metallic nanostructures and clusters [1, 2]. A plethora of new interesting concepts and applications is continuously emerging from that field of study [2]. In principle, the optical response of metals, which can be physically understood as the collective oscillations of the conduction electrons in metals [1], can be effectively tailored by the size, shape and the host material of these scatterers. Although analytical treatments can reveal some insightful design guidelines in simple structures [1, 3, 4], however, analytical methods fail to provide very good estimations for the case of arbitrary shaped single particles and more complex clusters.

Firstly, a rather simple and straightforward analytical treatment can be done under the electrostatic approximation perspective. Meanwhile, some important observations and conclusions can be drawn, limited only to particles or clusters small enough with respect to the illuminating wavelength, [3, 4]. More physical insight can be obtained by the Lorenz–Mie scattering theory, in which the electrodynamic scattering problem is solved, only for a few canonical shapes [1, 5]. Due to the advances of sophisticated nanofabrication techniques structures of increased complexity are feasible. Therefore, a numerical method, that can calculate the optical response of arbitrarily shaped particles and clusters, is necessary. Several approaches have been reported so far [5, 6, 7, 8], providing us with a wealth of information regarding these numerical methods. In our work, the surface integral equation method (SIE) is implemented, as a robust and precise method [8, 9, 10] to obtain and study the scattering response (efficiencies, near field, e.t.c.) of geometrically and materially complex single structures and clusters.

Turning to the details, our analysis focuses on the calculation of the near field patterns at the resonant wavelengths, or resonant modes [7] of various shapes such as spheres, ellipsoids, parallelepipeds, and core-shell structures. Here we demonstrate the near fields and the scattering, absorption and extinction efficiencies of a silver sphere, using the Drude model. Particularly, in Figure 1, the near field is depicted for a silver sphere of \(d = 100\,\text{nm}\) diameter. Note that the two main resonances can be clearly distinguished by their dipole and quadrupole characteristics; a result that is in excellent agreement with Lorenz–Mie theory, stating that the used method provides us with great physical insights. Moreover, the response of many other arbitrary shapes can be easily studied with the SIE method. In conclusion, SIE can offer a clear, robust, and efficient visualization of the near field distribution for a wide variety of particles and cluster shapes. As a result, the necessary physical insight is acquired towards the understanding of the plasmonic behavior, enabling the precise tailoring of the near field response which, after all, has a major impact on the overall composite material behavior.

ACKNOWLEDGMENT

The authors acknowledge the Aalto ELEC Doctoral School funding and the Aalto Energy Efficiency Research Programme (EXPECTS project) for the financial support.

REFERENCES

Figure 1: Scattering, extinction and absorption efficiencies (center) of a silver sphere with \(d = 100\) nm diameter. The real electric (up left) and imaginary magnetic field (up right) at \(\lambda = 353.7\) nm, and the imaginary electric (down left) and real magnetic (down right) component of the near field at \(\lambda = 400.07\) nm. The quadrupole (upper figures) and the dipole (lower figures) behavior can be clearly seen. In all four pictures a z-propagating, \(E_x\)-polarized incident wave implied.