ELS-XV-2015 Abstracts
ELS-XV-2015-141-1
Electromagnetic & Light Scattering XV 2015, Leipzig

Simulation of temporal response of plasmonic nanoparticles with time-domain discrete-dipole approximation

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We develop the time-domain discrete dipole approximation (DDA), describing the temporal evolution of electric field in plasmonic nanostructures. The precedent DDA in time-domain relies on the frequency-domain calculation followed by conversion to the time-domain. By using such indirect method, dynamically accounting for the temporal evolution of nonlinear or intensity-dependent response is impossible. The purpose of this work is to develop a novel simulation method providing directly the time-domain responses of nanosparticles.

The main equation is obtained by taking the inverse Fourier transform of the Taylor expansion of the frequency-domain DDA in terms of frequency deviation from the central frequency. Thus we assume that incident wavefronts of different frequencies accumulate relatively small phase difference when passing the particle. This assumption is always valid for nanoparticles much smaller than the wavelength. Being the time-domain method, the proposed approach also requires an analytic frequency dependence of electric permittivity, e.g. the Drude model.

We present numerical results of application of the time-domain DDA to silver nanosphere, rod, and disk, which agree well with that obtained with its frequency-domain counterpart and the finite-difference time-domain method. Moreover, the time-domain DDA is the fastest of the three methods for incident pulses of several-femtoseconds width. Thus, it can effectively be applied for modeling the temporal responses of plasmonic nanostructures. By using the Lorentz model for the dielectric materials, it can also be applied for time-domain response of dielectric nanostructures. We also discuss how it can be extended to simulation of ultrafast nonlinear processes, including spasers containing saturable gain and gain-assisted loss-less metamaterials.