Analysis of Electromagnetic Wave Interactions on Nanostructures with Non-local Dispersion Effects using a Volume Integral Equation Solver

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Continuous advances in fabrication techniques have enabled smaller and smaller plasmonic structures to be built. Oftentimes, electrical properties of these nanostructures/nanoparticles are accounted for using "localized" approximations such as the classical Drude model (S. A. Maier, *Plasmonics: Fundamentals and Applications*, 2007). However, when the size of these structures is much smaller than the wavelength of the excitation, localized models become inaccurate (Mortensen, et al., 2014, Nat. Commun. 1-7). To this end, non-local models, i.e., spatial dispersion models, where the constitutive relation does not only depend on the field at the considered position but also the field distribution within its close proximity (N. Schmitt, et al., 2016, J. Comput. Phys., 316, 396-415), have been developed. One way to incorporate these models into numerical electromagnetic analysis is to solve a coupled system of Maxwell and hydrodynamic equations. The former accounts for the interactions between fields, fluxes, and sources while the latter models the interactions of electrons with fields. Previously, a discontinuous Galerkin time domain scheme (DGTD) has been developed to solve this coupled system with a linearized non-local spatial dispersion model (N. Schmitt, et al., 2016, J. Comput. Phys, 316, 396-415). Additionally, a finite difference time domain (FDTD) method has been developed to analyze a terahertz (THz) plasma-wave device where a hydrodynamic Drude model is used to account for the constitutive relation within the two-dimensional (2D) electron gas (S. Bhardwaj, et al., 2018, IEEE JMMCT, 3, 29–36).

In this work, a volume integral equation (VIE) solver is developed to analyze electromagnetic field/wave interactions on subwavelength plasmonic scatterers. A VIE solver is preferred over FDTD and DGTD since it discretizes only the volume of the scatterer reducing the total number of unknowns and does not require approximate absorbing boundary conditions to truncate the unbounded physical domain into the finite computation domain. On the scatterer, two equations are enforced: (i) The VIE, which relates the incident electric field and (unknown) electric flux induced inside the scatterer, and (ii) the hydrodynamic equation, which relates the (unknown) electric flux and the (unknown) hydrodynamic current. The volume of the scatterer is discretized using tetrahedral elements and the unknowns are expanded using the well-known Schaubert-Wilton-Glisson (SWG) basis functions. Inserting these expansions into the coupled system of the VIE and the hydrodynamic equation and Galerkin testing the resulting equations yield a matrix equation in unknown expansion coefficients. This matrix equation can be solved using an iterative method or a direct method following a reduction of unknowns by substitution.

Numerical examples, which show the accuracy and the applicability of the proposed method in analyzing the non-local response of nanoparticles, will be presented.