Internship proposal (Master 2)
Spring 2017

Efficient finite element type solvers for the numerical modeling of nanoscale light/matter interaction

Nachos project-team[1], Inria Sophia Antipolis-Méditerranée, France.
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Description and objectives of the study

Nanostructuring of materials has opened up a number of new possibilities for manipulating and enhancing light-matter interactions, thereby improving fundamental device properties. Low-dimensional semiconductors, like quantum dots, enable one to catch the electrons and control the electronic properties of a material, while photonic crystal structures allow synthesizing the electromagnetic properties. These technologies may, e.g., be employed to make smaller and better lasers, sources that generate only one photon at a time, for applications in quantum information technology, or miniature sensors with high sensitivity. The incorporation of metallic structures into the medium adds further possibilities for manipulating the propagation of electromagnetic waves. In particular, this allows subwavelength localization of the electromagnetic field and, by subwavelength structuring of the material, novel effects like negative refraction, e.g. enabling super lenses, may be realized. Nanophotonics is the recently emerged, but already well defined, field of science and technology aimed at establishing and using the peculiar properties of light and light-matter interaction in various nanostructures. Nanophotonics includes all the phenomena that are used in optical sciences for the development of optical devices. Therefore, nanophotonics finds numerous applications such as in optical microscopy, the design of optical switches and electromagnetic chips circuits, transistor filaments, etc. Because of its numerous scientific and technological applications (e.g. in relation to telecommunication, energy production and biomedicine), nanophotonics represents an active field of research increasingly relying on numerical modeling beside experimental studies.

Numerical modeling of nanoscale light/matter interaction requires solving the system of Maxwell equations possibly coupled to appropriate models of physical dispersion such as the Drude and Drude-Lorentz models. The Finite Difference Time-Domain (FDTD) method introduced by K.S. Yee in 1996 is a widely used approach for solving the resulting system of partial differential equations (PDEs). In this method, the whole computational domain is discretized using a structured (Cartesian) grid. Due to the possible straightforward implementation of the algorithm and the availability of computational power, FDTD is often the method of choice for the simulation of time-domain nanoscale light/matter interaction problems. However, the space and time scales that characterize the underlying physical phenomena, in addition to the geometrical characteristics of the considered nanostructures, are particularly challenging for an accurate and efficient application of the FDTD method. In this internship, we propose to devise alternative numerical methods that are high order accurate in space and time and well suited to the use of locally refined unstructured grids. For that purpose, we will consider a particular form of finite element (FE) type method that has been recently introduced for the numerical treatment of model time-domain electromagnetics problems, and that will be adapted here to the nanophotonics setting. This particular FE formulation is referred as the Hybridized Discontinuous Galerkin (HDG) method.

[1] http://www-sop.inria.fr/nachos

A first goal of this study will be to devise such a HDG formulation for the discretization in space of the system of time-domain Maxwell equations coupled to a generalized dispersion model that can be fitted to describe the behavior of a wide range of metallic nanostructures. Then, a second important objective of this project will be to study several time integration strategies (explicit and hybrid explicit/implicit) with the goal of preserving high order accuracy in time while dealing efficiently with the time-step limitation induced by the local refinement of the grid. Finally, the resulting numerical methodology will be applied to the simulation and study of several concrete nanophotonics applications in collaboration with physicists.

Requirements
Master 2 in applied mathematics or scientific computing
Basic knowledge of electromagnetics
Good skills in programming; knowledge and experience of Fortran 9x/200x will be appreciated

Practicalities
Salary net per month: about 540 €
Duration: 6 months
Location: Inria Sophia Antipolis-Méditerranée research center