COMSOL Multiphysics® Investigation of Radiative and Nonradiative Channels of Quantum Emitter Fluorescence Near Hyperbolic Metamaterial

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Abstract

Introduction
Effective control over single atom emission might lead to major breakthrough in the field nanotechnology and make possible to create huge variety of novel devices. It is believed that use of so-called hyperbolic metamaterials (metamaterials with hyperbolic dispersion, HMM) can be helpful. In such materials dielectric permittivity tensor is extremely anisotropic — one or two of its diagonal components are negative while the others are positive. Because of this feature waves with arbitrary large wavevectors can propagate through such metamaterials, which lead to high fluorescence rate of quantum emitters placed near them [1]. However, definition of problem with hyperbolic medium can be complicated from the mathematical point of view. So we wanted to check whether COMSOL Multiphysics® will be able solve this problem and compare numerical solution with analytical one. Then our goal was to investigate radiative and nonradiative channels of dipole radiation near HMM and find optimal parameters in order to maximize emission of radiation.

Use of COMSOL Multiphysics®
COMSOL Multiphysics® was used to model interaction of electric dipole with effective HMM (uniform anisotropic media with hyperbolic dispersion) and calculate emission rate of dipole in comparison to that value in the absence of metamaterial (model setup on Figure 1). As a first step we considered vertical orientation of electric dipole moment, in this case problem is axisymmetric. COMSOL Multiphysics® doesn't have dipole node in 2D axisymmetric formulation, so we had to add a weak contribution node to the point on the symmetry axis representing oscillating current in the vertical direction.

Once optimal parameters for HMM was found, dielectric nanoantennas of certain shape were placed on the surface of HMM (see Figure 1) in order to provide narrow directivity pattern of the emitted light. Parameters of these nanoantennas were found with COMSOL Multiphysics® Optimization Module.

Results

Modeling results were proven to be accurate by comparing them to analytical ones. A regime was found when radiative rate of dipole, placed near HMM slab with nanoantennas, is almost 10 times higher than that of dipole in vacuum (see Figure 2). It is important that in this case radiative rate is considerably higher than nonradiative one along with high directivity of emitted light.

Conclusion

We showed that COMSOL Multiphysics® can solve RF problems with hyperbolic media. We found regime that can be used in practical applications.

Reference

1. Y. Guo, W. Newman, C. Cortes, and Z. Jacob, Applications of hyperbolic metamaterial substrates, Advances in OptoElectronics (2012).

Figures used in the abstract

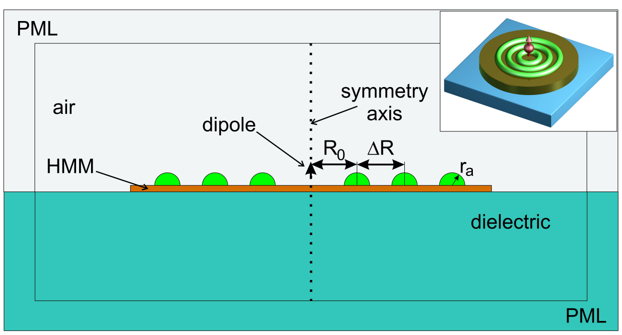

Figure 1: Geometry of the axisymmetric problem solved in COMSOL. On the symmetry axis there is a vertical electric dipole. Green half-circles – dielectric nanoantennas (problem was solved with and without them). In the inset there is a 3D view of the setup with nanoantennas.

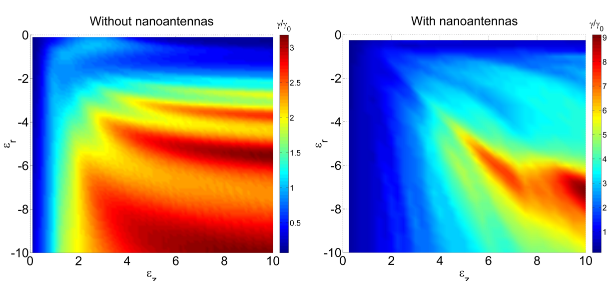

Figure 2: Relative radiation rate of electric dipole placed near HMM (left) and near HMM with nanoantennas (right).