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Subject: Research Proposal

Proposed Research Topic: Visualization and Algorithm for Simulations of Electro-Magnetic Field in an Elementary Cell of a Layer of Metamaterials.

Introduction: Metamaterials are artificial materials that have nano scale metallic inclusions in a dielectric host medium. Due to this structure, electric and magnetic fields in metamaterials interact resonantly with free electrons of metallic inclusions. One of the results of this electromagnetic interaction with metamaterials is negative refraction. The metamaterials with negative refraction are called negative refractive index materials. When light interacts with these materials, it has two resonances, electric and magnetic. Metamaterials are layered structures, and every layer is periodic in its plane and homogeneous in the transverse direction, as seen in the following pictures (most of the information in introduction comes from [3]).

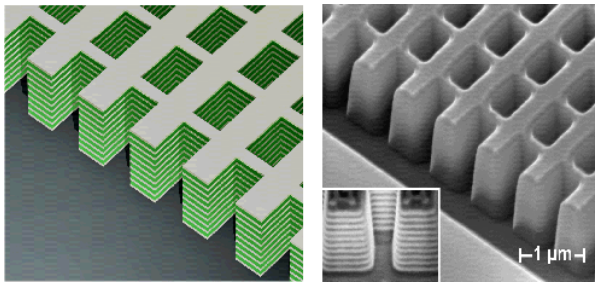


Figure 1. Multi layered metamaterial.
Taken from [2].

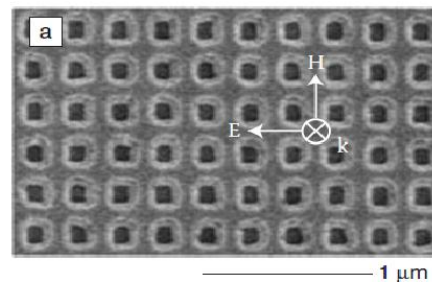


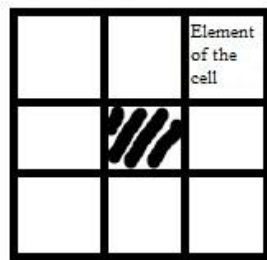
Figure 2. Sample of single-layer of metamaterial with negative refractive index. Taken from [1].

This periodicity of layers is explicitly used in derivation of governing equations that describe electric and magnetic fields.

Purpose: Metamaterials are very expensive to fabricate. Therefore, numerical simulations have advantage of being cheaper than actual experiments with metamaterials. In addition, materials with negative refractive index bend light in an unusual way, so the combination of materials with positive and negative refractive indexes can create a material with zero refractive index. Metamaterials with negative refractive index can be used to create super lens that will resolve objects whose sizes are smaller than the wavelength of light. My project will concentrate on performing simulations of light propagation through metamaterials with negative refractive indexes.

Plan:

1. I am going to read “New Algorithm for Simulation of the Metamaterials” by Alexander O. Korotkevich, Xingjie Ni, Alexander V. Kildishev and “Course of General Physics” volume 3, Electricity by Sivukhin D.V.
2. I will use a model that includes the following parts:
 - For the simplicity, I will consider a 2D case of a single layer of metamaterial where light waves propagate along transverse direction. A cell from a layer looks like this:



Every element of the cell or structure has boundaries.

- I will express electric and magnetic fields in every element of the structure in the form of the plain waves' expansion (interior of every element of the structure is homogeneous) with unknown coefficients.
 - The chain of these equations is formed from the conditions of continuity of the tangential components of electric and magnetic fields on every boundary in the cell. Boundary conditions follow from Maxwell's equations in a dielectric. Thin metal films at optical frequencies can be considered as a material with complex dielectric permittivity.
 - Since the problem explicitly includes the positions of the boundaries of the elements of the periodic cell, problems due to piece-wise constant dielectric permittivity function are avoided.
3. As a result, I get an eigenvalue problem. Eigenvectors, which are solutions of this problem, are eigenmodes for fields in the structure. So, we can represent any field in the structure as a linear combination of eigenmodes. So, I will need to find eigenmodes in the structure. Using governing equations, I will derive recurrent formulas for the calculation of the coefficients.

- I will write a code which will calculate these coefficients by using recurrent formulas mentioned above. After I will find these coefficients, I will be able to write a code that reconstructs and visualizes eigenmodes for electric and magnetic fields.
4. Since the layer is periodic in its plane, the electric and magnetic fields that I got from the mentioned above cell are the same in other cells. So, I am able to find electromagnetic field in the whole layer.

References

- [1] Uday K. Chettiar, Shumin Xiao, Alexander V. Kildishev, Wenshan Cai, Hsiao-Kuan Yuan, Vladimir P. Drachev and Vladimir M. Shalaev (2008). Optical Metamagnetism and Negative-Index Metamaterials. *MRS Bulletin*, 33 , pp 921-926 doi:10.1557/mrs2008.200
- [2] Jason Valentine, Shuang Zhang, Thomas Zentgraf, Erick Ulin-Avila, Dentcho A. Genov, Guy Bartal & Xiang Zhang (18 September 2008). Three-dimensional optical metamaterial with a negative refractive index. *Nature*, 455, pp 376-379 doi:10.1038/nature07247
- [3] Alexander O. Korotkevich. Research Proposal: Effective Algorithm for Simulation of Perspective Nanoscaled Metamaterials. In preparation.