THz manipulation and superlensing using polaritonic metamaterials

M. Kafesaki[1], A. Reyes-Corronado[1], S. Foteinopoulou[2], G. Kenanakis[1], N. Katsarakis[1], M. A. Acosta[3], R. I. Merrino[3], V. M. Orera[3], V. Myroshnychenko[4], J. de Abajo[4], E. Economou[1], C.M. Soukoulis[1,5]

[1]Institute of Electronic Structure and Laser, Foundation for Research and Technology Hellas (FORTH), P.O. Box 1385, 71110, Heraklion, Crete, Greece
Fax: + 30–2810-391569; email: kafesaki@iesl.forth.gr
[2] School of Physics, University of Exeter, Exeter, UK
[3] Instituto de Ciencias de Materiales de Aragon, CSIC-Universidad de Zaragoza, 50018 Zaragoza, Spain
[4] Instituto de Optica, CSIC, Madrid, Spain
[5]Ames Lab. And Dept. of Physics, Iowa State University, Ames, Iowa, USA

Abstract

In this paper we discuss and demonstrate the potential of composite metamaterials made of polaritonic rods in a host to exhibit negative refraction and subwavelength imaging resolution in the THz regime, giving thus the ability to those structures to be used in a variety of THz manipulation components.

1. Introduction

Polaritonic materials are polar crystalline materials characterized by a resonant permittivity regime in the far IR, as a result of the excitation of optical phonons. This resonant permittivity (see Fig.1b and 1c) is characterized by large positive values (where the material behaves as high index dielectric) and negative values, where the material behaves as metal. Thus polaritonic materials can replace metals or high index dielectrics [1], [2], in THz metamaterials, offering the possibility for negative effective permittivity and permeability, polarization or absorption control, etc, by choosing properly the structure geometry.

In this work we study, both theoretically and experimentally, metamaterial structures made of polaritonic rods in a polaritonic host material. We show that in the regime where rods show negative permittivity response such a system behaves as indefinite medium [3] (i.e. anisotropic system with a negative permittivity, ε, component), which leads to capability for negative refraction and focusing with sub-wavelength resolution [4]. Such capabilities are demonstrated with both simulations and experiments.

2. Results and discussion

The particular systems that we are based on are LiF rods in NaCl in hexagonal lattice (see Fig. 1a) and LiF rods in KCl. The fabricated samples have been obtained using eutectics self-organization and have LiF filling ratio 25% for the LiF-NaCl system and 6.95% for the LiF-KCl one. The nearest neighboring rod separation, a, can be controlled at the stage of fabrication and varies between 3.6 and 20.3 μm for the LiF-NaCl systems and between 2.8 and 11.2 μm for the LiF-KCl. The rod radius changes proportionally to a, as to keep the filling ratio constant.

ISBN 978-952-67611-0-7

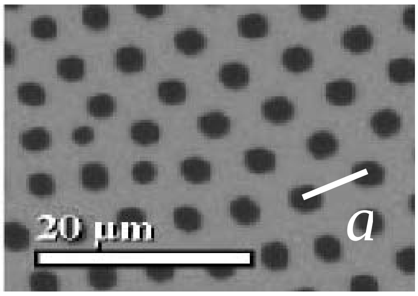

Fig. 1(a): Photo of a cross-section of the sample under study. Cylinders are LiF (black areas) and host NaCl (grey areas).

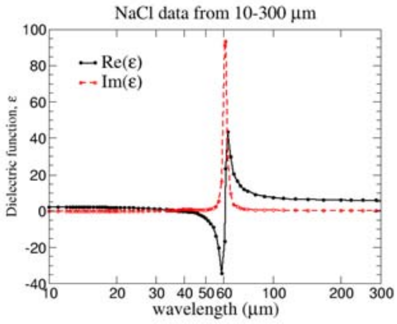

Fig. 1(b): Permittivity of the NaCl phase – data from Handbook.

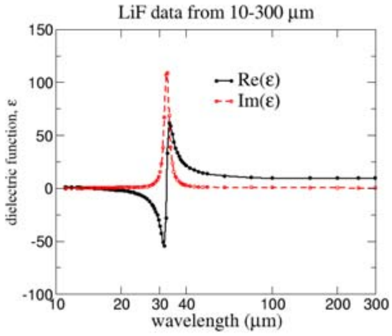

Fig. 1(c): Permittivity of the LiF phase – data from Handbook.

In what follows we are restricted in the system of LiF rods in NaCl (see Fig. 1a) with a=3.6 µm. For this system the electromagnetic response can be described by quasistatic effective medium formulas such as Maxwell-Garnet or Bruggeman formulas [5]. Using such formulas it is found (see Fig. 2) that at the regime where the rods show negative permittivity (~30 µm) the overall system is characterized by an effective permittivity which is negative if electric field is parallel to the rods (E-polarization) and positive if magnetic field is parallel to the rods (H-polarization).

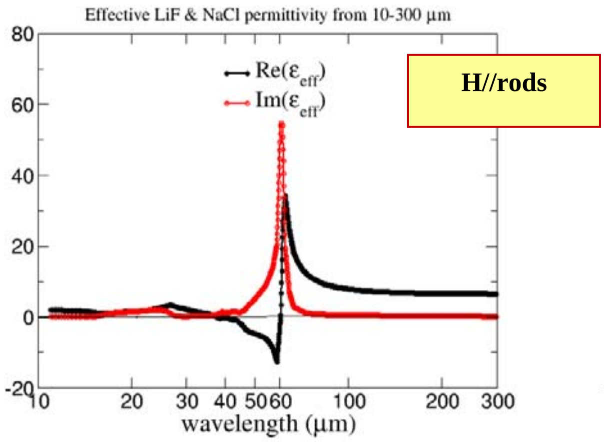

Fig. 2(a): Effective permittivity, ε_{eff}, for the LiF/NaCl sample for H-polarization (using Bruggeman formula).

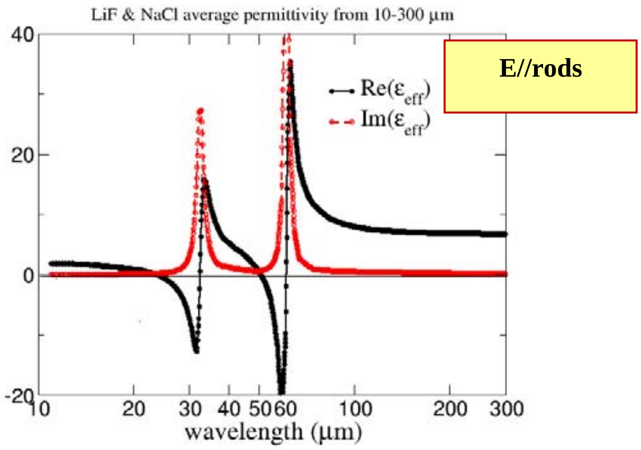

Fig. 2(b): Effective permittivity, ε_{eff}, for the LiF/NaCl sample for E-polarization.

The applicability of the effective medium formulas for our structure is verified by reflection measurements of the actual eutectic system. The results are shown in Fig. 3 – red lines, where the regimes of negative effective ε of Fig. 2 coincide with reflection peaks.

Anisotropic systems like our rods system which are characterized by a permittivity that is negative for one polarization and positive for the others are called indefinite media [3]. Their main feature for our interest is the hyperbolic dispersion relation, which can lead to negative refraction and subwavelength resolution imaging (the latter due to the transformation of evanescent modes to propagating in the hyperbolic medium).

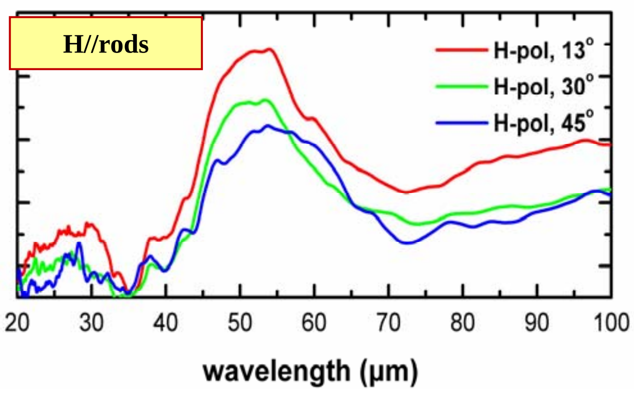

Fig. 3(a): Measured reflection coefficient of the LiF/NaCl sample for H-polarization and for various crystal directions.

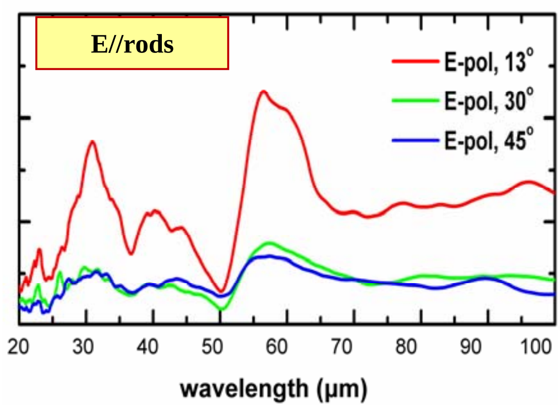

Fig. 3(b): Same as Fig. 3(a) for E-polarization.

To demonstrate superlensing in such a system one needs to calculate the equifrequency contours, i.e. the contours of constant frequency in the wavevector space, as to estimate the angles of refraction and the proper rod length (resulting from Fabry-Perot resonance condition) to achieve total transmission. A preliminary simulation demonstrating such lensing is shown in Fig. 4. Detailed simulations and experimental data will be discussed in the presentation.

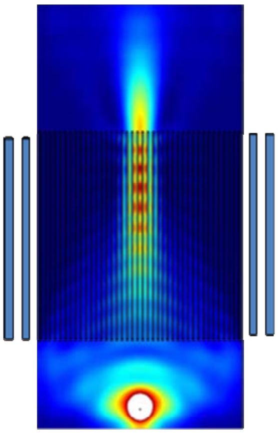

Fig. 4: A simple example demosntrating the focusing capability in the LiF/NaCl system. Neither of the parameters of the system has been optimized for focusing.

3. Conclusion

Periodic metamaterials made of polaritonic rods in a host can behave as anisotropic indefinite media, showing negative refraction and subwavelength resolution imaging capabilities at the THz wave regime. These capabilities will be discussed and demonstrated in the talk.

References

[1] J.B. Pendry et. al., Magnetism from Conductors and Enhanced Non-linear Phenomena, *IEEE Trans. MIT.,* v. 47, p. 2075, 1999; J.B. Pendry et. al., "Extremely Low-frequency Plasmons in Metallic Mesostructures", *Phys. Rev. Lett*., vol. 76, , p. 4773, 1996.

[2] S. O'Brien, and J. B. Pendry, Photonic band-gap effects and magnetic activity in dielectric composites, *J. Phys.*, vol. 14, pp. 4035-4044, 2002.

[3] D. R Smith, D. Schurig, Electromagnetic wave propagation in media with indefinite permittivity and permeability tensors, *Phys. Rev. Lett.*, v. 90, p. 077405, 2003.

[4] J.B. Pendry, Negative Refraction Makes a Perfect Lens, *Phys. Rev. Lett.*, vol. 85, p. 3966, 2000.

[5] Shivola, *Electromagnetic mixing formulas and applications*, The Institute of Electrical Engineers, London, 1999.