Planar THz metamaterial with chiral symmetry breaking

Justyna Fabiańska, Florian Enderli and Thomas Feurer

Institute of Applied Physics
University of Bern
Sidlerstrasse 5, CH-3012 Bern, Switzerland
Fax: +41-(0)31 631 37 65; email: justyna.fabianska@iap.unibe.ch

Abstract

We demonstrate a planar metamaterials with chiral symmetry breaking array in THz frequency range. Our results show that applying very interesting chiral metamaterial with the two x and y polarization induces the split of the transmission peak and it strongly afftects on the behavior of the electric field in the two resonances.

1. Introduction

Metamaterials are artificial structures consisting of arrays of subwavelength electromagnetic resonators and present artificial electric and magnetic responses [1]. These materials are promising for optical to microwave applications, such as super lensing [2], invisibility cloaking [3] or as a negative refractive index material [4, 5]. Metamaterials allow for intriguing possibilities in designing materials with a controlled photonic response [6]. Metamaterials can also allow both field components of light to be coupled to meta-atoms, enabling entirely new optical properties and exciting applications with such 'two-handed' light [7]. The structural units of metamaterials can be tailored in shape and size. One of the most exciting opportunities for metamaterials is the development of negative-index materials (NIMs). These NIMs bring the concept of refractive index into a new domain of exploration and thus promise to create entirely new prospects for manipulating light, with revolutionary impacts on present-day optical technologies [7]. The response of metamaterials is mostly analyzed in the far-field regime, which provides information about the resonant behavior. One of the most prominent examples is an array of metallic rings with a gap, so called split ring resonators (SRRs). These SRRs exhibit several resonant responses where a combination of charge accumulations and current flows of increasing order are excited on the structure [6]. Using an incident electromagnetic wave for excitation, several resonant modes are excited on the structure [8].

However, the chiral metamaterials are still one of the missing kind of these materials. It was shown recently that the introduction of the planar metamaterial with chiral symmetry breaking leads to the split of the transmission peak [9]. These studies revealed the large influence on the optical rotation and circular dichroism as well as the optical properties of chiral metamaterials in the visible region [9].

Here we study the corresponding structure to this paper [9] but in THz range. The terahertz (THz) frequency range is of particular interest for the investigation of metamaterials since THz time-domain spectroscopy (THz TDS) techniques can resolve the amplitude, phase, and polarization of the electromagnetic fields [6]. We present near-field measurements of planar THz metamaterials with chiral symmetry breaking as well as numerical simulations. We investigate electric field distribution of THz pulses propagating through planar metamaterial single structure with the chiral symmetry.

ISBN 978-952-67611-2-1

2. The planar THz metamaterial with chiral symmetry breaking as an example for study

We used a planar metamaterial design to study the effects of chiral symmetry breaking. Figure 1 shows the scheme of L-shaped chiral symmetry breaking. The design of the structure is consisted of four L-shaped arms. The lattice constant is P = 834 µm, the width of a single L-shaped arm is w = 15 µm, and the longer and shorter arm length is l_1 = 179 µm and l = 40 µm, respectively.

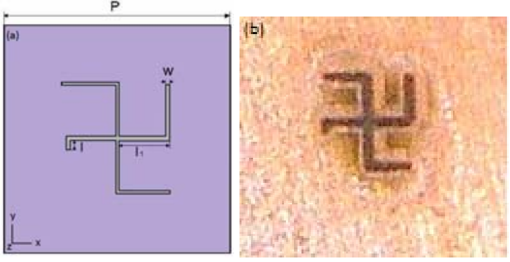

Fig. 1: a) Schematic illustration of planar metamaterial with chiral symmetry breaking, b) Microscope image of the sample.

In the experiment, the samples were prepared by laser maching into a 10 µm thick copper foil. A modified THz time domain spectrometer allows to measure the near and the far field of a sample placed in the THz beam. With a detector able to scan the transversal beam plane, a spatial resolution of λ/30 at 500 GHz and a sub 100 fs temporal resolution is achieved. By placing an additional Michelson Interferometer in the pump beam path, THz double pulses can be generated with a variable pulse to pulse delay. The numerical simulations were based on the finite element method (FEM) [10] using a commercial software package (COMSOL Multiphysics 3.5). The three dimensional simulations were carried out in the frequency-domain which allows to include the dispersive behaviour of copper as obtained from the Drude model [4]. The structure with chiral symmetry breaking was positioned in the center of a box shaped simulation domain. The plane electromagnetic wave was launched from one of the boundaries and the frequency was chosen as a scanned parameter.

3. Comparison of measurements and simulations

The experimental approach is based on electro-optic THz near-field imaging, allowing us to directly map the distribution of the out-of plane electric field component. This is ideal since the out-of plane (Ez) component is a direct measure of the induced charge accumulations representing the mode profile and since it is not superimposed by the components of the incident field. In the experiment the THz pulse in coming along the x axis and then the sample is rotated by 900. In the numerical simulation we consider E-field and H-field excitation. For the sample, the E, H, and k triad of the incoming THz field were oriented along the x, y, and z axes shown in Fig.1. The sample was placed in x-y plane.
The measured and simulated transmission spectra are presented in Figure 2.(a) and 2(b), respectively.

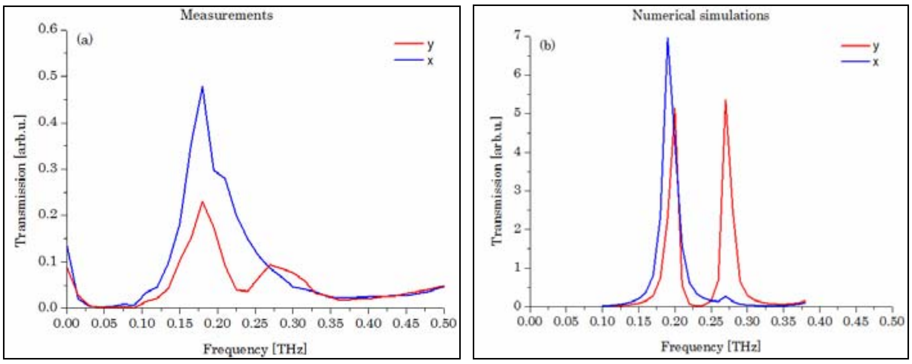

Fig. 2. a) Measured and b) simulated transmission spectra.

The red curves show the transmission spectra of the y-polarized wave and blue curves - x-polarized wave. In case when we have y-polarized wave in the numerical simulation, we received the two transmission peaks which appear at around 0.2 THz and 0.27 THz. If there is x-polarized wave, then only one peak occurs at 0.19 THz.

Comparing the near-field measurements, for the y-polarized wave we got the two transmission peaks (at 0.18 THz and 0.27 THz) and it appears only one peak for the x-polarized wave the same as in numerical simulations. To show more details, we plotted the simulated and measured distributions of the z-component of electric field for the two resonances of x- and y-polarized wave (Fig. 3).

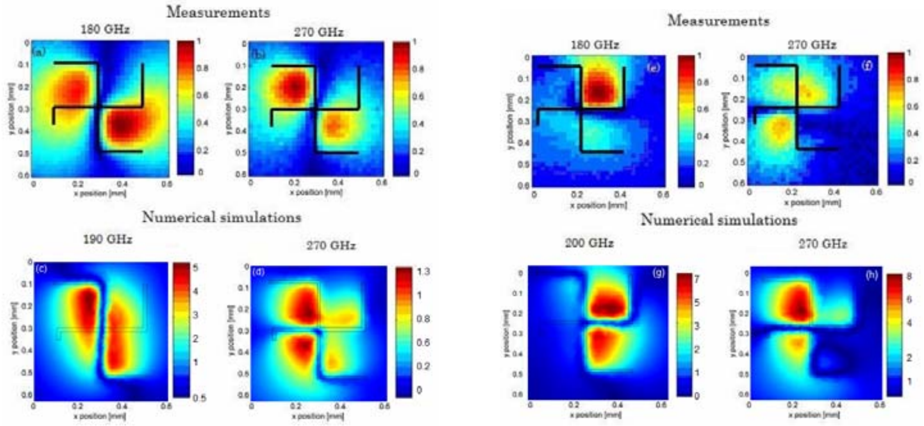

Fig. 3. Measured results (a), (b), (e), (f) and simulated (c), (d), (g), (h) for the transmission peaks for the frequency of 0.18 THz, 0.19 THz, 0.2 THz (column on the left side) and 0.27 THz (column on the right side). (a)-(d) denote the z component of the electric field for the x-polarized wave, and (e)- (h) - the z component of the electric field for the y-polarized wave. The electric field distribution was taken at z=60 μm above the surface.

In the x direction we have the same arm length of chiral structure. Therefore we receive only one resonance peak corresponding to the x-polarized wave. However, in the y direction there occur two different arm lengths: the longer and the shorter. Thus, it leads to observing the two resonances.

4. Conclusion

We have experimentally and numerically investigated a planar metamaterial single structure design to show the effects of chiral symmetry breaking in THz frequency range presenting near-field measurements as well. The results exhibit also the behavior of the electric field in the x and y direction. Applying very interesting chiral metamaterial with the two x and y-polarized waves induces observation of two transmission peaks and it strongly afftects on the behavior of the electric field in the two resonances. The THz near-field measurements with a success are comparable to numerical simulations.

References

[1] Koray Aydin, Imogen M. Pryce, Harry A. Atwater, “Symmetry breaking and strong coupling in planar optical metamaterials”, *Optic Express*, vol. 18, no.13, pp. 13407-13417, 2010
[2] J. Pendry, “Negative index makes a perfect lens”, *Phys. Rev. Lett.* Vol. 85, no.18, pp. 3966-3969, 2000
[3] J. Pendry, D. Schurig, and D. Smith, “controlling electromagnetic field”, *Science*, vol. 312, no. 5781, pp.1780-1782, 2006
[4] Ari Sihvola, “Metamaterials in electromagnetics”, *Metamaterials*, vol. 1, no. 1, pp. 2–11, 2007
[5] R. Shelby, D. Smith, and S. Schultz, “Experimental verification of a negative index of refraction”, *Science*, vol. 292, pp. 77-79, 2001
[6] H. Merbold, A. Bitzer, F. Enderli, T. Feurer, “Spatiotemporal Visualization of THz Near-Fields in Metamaterial Arrays”, *Journal of Infrared, Millimeter and Terahertz Waves*, vol. 32, no. 5, 2011
[7] Vladimir M. Shalaev,“Optical negative-index metamaterials”, *Nature Photonics*, vol. 1, 41 – 48, 2007
[8] C. Rockstuhl, F. Lederer, C. Etrich, T. Zentgraf, J. Kuhl, and H. Giessen, „On the reinterpretation of resonances in split-ring-resonators at normal incidence“, *Opt. Express*, vol. 14, no. 19, pp. 8827-8836, 2006
[9] Wan-xia Huang, Yi Zhang, Xia-mei Tang, Li-Sha Cai,Jun-wei Zhao, Lin Zhou, Qian-jin Wang, Cheng-ping Huang, Yong-yuan Zhu, “Optical properties of a planar metamaterial with chiral symmetry breaking“, *Optics Letters*, vol. 36, no.17, pp. 3359-3361, 2011
[10] J. Jin, *The Finite Element Method in Electromagnetics*. Willey-IEEE Press, Second ed., 2002