The development of chiral metasurface with tunable polarizing properties in THz frequency range

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***Abstract*—In this paper the theoretical study of different types of chiral metasurface based on gammadion crosses is demonstrated. The mechanisms of polarization and frequency tenability using graphene are proposed. Four experimental realizations of such metasurfaces with different geometry were manufactured using laser engraving. Spectral characteristics of the most precisely manusfactured metasurface were measured using terahertz time-domain spectroscopy.**

***Index Terms*—Terahertz metamaterials, polarization shift keying, frequency selective surfaces.**

I. Introduction

RECENT decades THz frequency range has become very popular in scientific society due to its unique properties and applications. Despite to this fact, a lack in passive components, especially different polarization converters, still exists for terahertz frequency range. The solution of the problem could be found in producing of metamaterials with different functionalities. Chiral metamaterials are widely known for their various applications, such as development of tunable reflectors, polarization filters, multispectral imaging, perfect absorbers, etc. In terahertz time-domain spectroscopy these metasurfaces can be used especially for polarization control and as sensors in biophotonics measurements.

In this paper we demonstrate the possibility of control the polarization state of the terahertz radiation using chiral metasurfaces. It was studied numerically that the polarization properties of chiral metasurface can be controlled by variation of the resonators geometry. To make these metasurfaces tunable, the resonators were partly replaced by graphene layers. The simplest realization of planar one-layer chiral metasurface was performed using laser engraving of a plastic (PET) sheet covered by a thin aluminium layer. The experimental measurements were performed using time-domain spectroscopy. Here below I summarized the main results of the project.

II. The Metasurface Under the Study

The basic unit cell consists of metallic resonator made of conjugated aluminum gammadion crosses on the plastic substrate with ε=3.5 (Fig. 1).

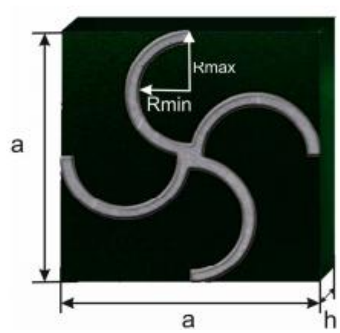
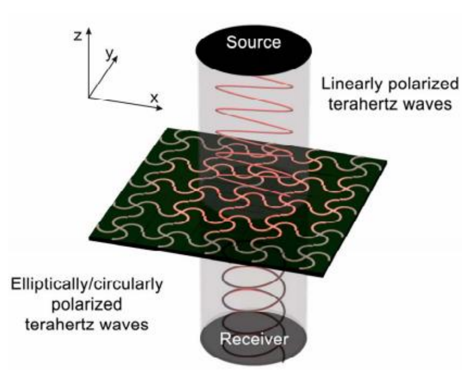


Fig. 1. The unit cell under the investigation. Rmax stands for the outer radius of the gammadion petal, Rmin is the inner radius of the one. The width of the petal is defined as w=Rmax-Rmin.

First of all we have studied the influence of the petal width on the resonant frequency of the metasurface. The numerical simulation was performed using finite-elements technique in frequency domain. The scheme of the numerical experiment is shown in Fig. 2.

It was found that the resonant frequency of the metasurface are strongly dependent on the gammadion petal width – they



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are increasing in values with enhancement of the petal width. The full results with polarization conversion can be found in the conference paper [1].

The next step of the project was the experimental realization of the metasurfaces. Using the results of numerical simulations we have chosen four variations of the metasurface with different width of petals. The prototypes were made using laser engraving and were studied using THz-TDS. The photos of the prototypes were captured using microscope and can be seen in Fig. 3.

It was found that all of the manufactured metasurfaces resonators have defects, and the most noticeable is truncation of the petals. The angle of truncations is about δ=25 degrees.

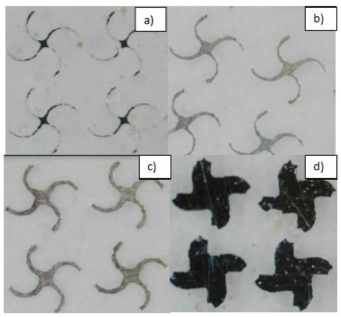

Fig. 3. Four prototypes of the investigated metasurface with differend width: a) w=40 µm, b) w=62.5 m, c) w=70 µm, d) w=132.5 µm

However, we simulated numerically the impact of this defect. It was revealed that this truncation leads to the shift (Δ=0.03 THz) of resonances to lower frequencies. The width error is not considered here, so, it is possible that this error leads to additional resonant frequencies shift. Then we used THz-TDS to measure the transmission of the most accurate metasurface with w=70 µm. Unfortunately, we have not measured yet the polarization ellipse because additional polarizers for ellipsometry were unavailable now. The final results can be

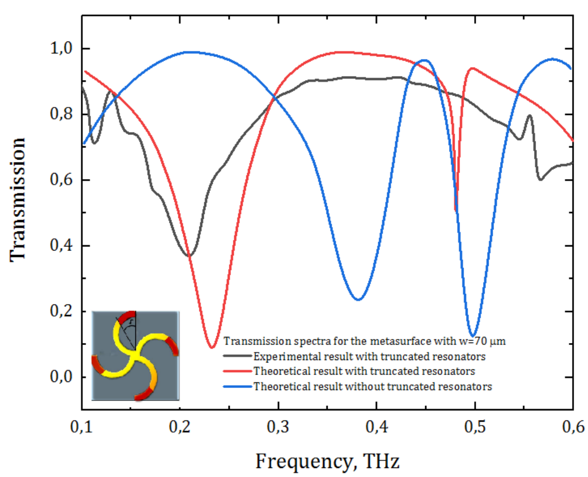

Fig. 4. Experimental results and theoretical calculation of transmission spectra for chiral metasurface with w=70 µm.

seen in Fig. 4.

Due to defects of the manufacturing, also it was decided to study the influence of the chiral element curvature on the polarizing properties of the metasurface. Unfortunately, due to the lack of space here, I do not put the results here, but they can be found in the paper [2].

Also it was found that it is possible to change the ellipse of polarization of the transmitted wave by graphene. If the resonator is partly made of graphene, the polarization state might be transformated by optical pumping. The results of this investigation were presented on SPB OPEN conference and will be published soon [3].

III. Conclusion

It is shown that chiral metasurface polarization conversion can be managed using geometry changes. These geometry changes also can be imitated using graphene includings. It should be noticed that laser engraving is not the best solution for the development of the metasurface.

The results of this project were partially shown on the 43rd IRMMW-THz conference, where I met a lot of famous scientists, such as X.-C. Zhang, M. Bakunov and others. It was a great pleasure to participate in the student's school on terahertz topics. Fruitful discussions of my presentations gave me some thoughts about next planes and applications of my own research.

The Scholarship made a great impact on my scientific work. Using the scholarship, I participated in Doctoral school on metamaterials for terahertz frequencies, where I got new actual knowledge on this topic. Also it enabled me to manufacture the experimental prototypes of my metasurfaces for the diploma work. As a result, I defended my bachelor's work with honors and won the prize for the best scientific bachelor thesis in ITMO University. Now I am the master's student at the same department, and next year I want to spend one semester in the University of Exeter (UK), where I am going to study the manufacturing process of metasurfaces for terahertz frequency range. After that I would like to earn PhD in Radio physics, where I want to develop a theory explaining the effects in chiral media and their possible applications in polarization components, may be in cloacking or even in development of new types of THz sources.

Acknowledgment

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