Graphene-based tunability of chiral metasurface in terahertz frequency range

M S Masyukov¹, A V Vozianova¹, A N Grebenchukov¹, M K Khodzitsky¹
¹Terahertz Biomedicine Laboratory, ITMO University, St. Petersburg 197101, Russia

Abstract. This paper is devoted to bi-layer chiral metasurface with graphene half-petals. Numerical simulation in CST Microwave Studio confirms that changing of chemical potential of graphene leads to changing in transmission coefficients for this metasurface. Due to chirality, these coefficients are different for right-handed and left-handed circularly polarized wave. Thus, such metasurface can be used as tunable polarization-converter.

Introduction

Recent decades THz frequency range has become very popular in scientific society due to its unique properties and applications in space exploration, tomography [1] and biomedicine [2-4], etc. Despite to this fact, a deficit of passive components still exists for terahertz frequency range. The solution of the problem could be found in development of metamaterials with different functionalities. Metamaterials or artificial effective media are consisted of an array of unit cells and show different effects that cannot be found in nature, for example, negative refraction index. Such phenomenon had been predicted theoretically by V. Veselago in 1967 [5], although it was confirmed experimentally many years later by D. Smith and others in 1999 [6]. This pioneer work initiated a big increase in research on metamaterials. Metamaterials have different applications, such as tunable reflectors, switchers, filters, and perfect absorbers [7-9] and especially they are used in polarization components. Chiral planar metamaterials, or chiral metasurfaces, show negative refractive index, circular dichroism, etc. These unique properties allow applying chiral metamaterials in polarization optics. In this work we propose a tunable polarization converter – a bi-layer chiral metasurface that is composed of conjugated gammadion resonators with graphene inclusions.

The metasurface under the study

The unit cell of the investigated metasurface [10-11] is shown in Fig. 1. The geometrical parameters are following: the side of the unit cell a=600 µm, a width of the planar gammadion petal w=10 µm (its inner radius Rmin=140 µm), the silicone substrate thickness is 45 µm and permittivity ε=11.34. The back side resonator is made entirely of perfect electric conductor (PEC), while the front resonator half-part has been replaced by graphene.
Two variations of the metasurface were studied. In the first case the center of the top resonator was made of PEC and the edges of the gammadion petals were made of graphene (as shown in Fig. 1-a). In other case the metallic and graphene parts were reversed.

The numerical simulation and polarizing properties calculation approach

The transmission simulations for linearly polarized waves were performed in frequency domain using CST Microwave Studio based on Finite Elements Method. For each design the unit cell was translated along x and y axes directions. A scheme of the numerical simulation can be found in Fig. 3.

To calculate the polarization properties of the metasurface one needs to evaluate the transmission spectra for circularly polarized waves. These spectra can be simply calculated from the simulated co- and cross-polarization transmission coefficients $T_{xx}$ and $T_{xy}$ respectively by using Jones calculus approach [12] for the structures with fourfold (C4) rotational symmetry:

$$\begin{pmatrix} T_{++} & T_{+-} \\ T_{-+} & T_{--} \end{pmatrix} = \begin{pmatrix} T_{xx} + iT_{xy} & 0 \\ 0 & T_{xx} - iT_{xy} \end{pmatrix}$$

(1)

where $T_{+-}$ refers to the transmission amplitudes for right-handed circularly polarized waves, $T_{-+}$ to the left-handed ones respectively. Having the transmission amplitudes for circularly polarized waves calculated, the ellipticity angle $\eta$ was found using the next formula:
When the ellipticity angle reaches $\eta = +45$ degrees, it corresponds to the right-handed circular polarization of the transmitted wave, while $\eta = -45$ degrees corresponds to the left-handed circular polarization of the transmitted wave. The intermediate values of the ellipticity refer to the elliptically polarized waves, and when $\eta = 0$ the polarization is linear.

**Results**

The ellipticity angle spectra were calculated for six values of graphene chemical potential for both metasurface types in the frequency range of 0.1 – 0.2 THz.

![Figure 3. The ellipticity angle spectra for two types of the metasurface: a) original metasurface; b) metasurface with inverted materials of the top side resonator](image-url)
The results shown in Fig. 2 represent the strong dependence of polarizing properties on chemical potential of graphene. The polarization state of the transmitted wave can be changed by varying of the chemical potential of graphene from 0 to 0.5 eV. As we can see, this dependence is almost the same for both structures around the frequency of 0.145 THz, but quite different for the resonance at 0.178 THz: for the original metasurface design maximal value of the ellipticity angle is $|\eta_{\text{max}}|=38$ degrees, for the second design $|\eta_{\text{max}}|=43$ degrees. This effect is caused by replacing parts of graphene by PEC on the front side resonator. Due to the fact that the material of the back side resonator was not changed, we can suppose that the ellipticity extreme at 0.145 was caused by the resonances from this resonator. The second extreme in this frequency range may depend on the resonance from the hybrid front resonator.

Conclusions

In summary, the influence of graphene inclusions on chiral metasurface polarizing properties has been studied. It was found that the ellipticity angle depends on the Fermi level of the graphene inclusions. The noticeable changes of ellipticity provide a possible wide usage of the metasurface as a tunable polarization converter in many applications, for example, terahertz polarimetry, terahertz time-domain spectroscopy, etc.

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