Calculation of chiral metasurface characteristics in terahertz frequency range

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Abstract. In this work the ellipticity and quantity of optical activity for chiral metasurface in terahertz frequency range were obtained. The analysis of the changing of metasurface polarizing properties depending on gammadion petal ellipse was made. The numerical simulation for structure under investigation using finite element method was performed.

1. Introduction

Although chirality has been known for a long time, recently chiral structures are of interest both for fundamental physics and for applications [1-2]. Chirality is a property of asymmetry when an object is distinguishable from its mirror image. Hence, breaking the symmetry enables the manipulation of polarization states. Terahertz (THz) technology has made great advance in the fields of biological samples analysis, THz imaging, high-speed wireless communication and so on. To the further development of THz technology, there is also a high demand for the tunable and functional devices [3-7]. This is especially interesting for control and manipulation of the polarization conversion at THz frequencies [8-10] because of their significant applications [11-14]. One of the chiral structure designs under investigation is an array of twisted gammadion crosses with fourfold rotation symmetry. It was shown strong rotator power in the visible and near-IR spectral ranges for such double –periodic bilayered structure [15]. It was experimentally and numerically demonstrated the possibility of a chirality induced by negative refractive index [16]. The influence of twisted gammadion crosses curvature on polarization rotation was shown in [17-18]. It was shown [19] the ability of polarization properties control by gammadion petal width changing.

In this work we consider chiral metasurface consisted of periodic array of twisted gammadion crosses placed on silicon substrate at THz frequencies. We studied the influence of the ratio of the ellipses semiaxes forming the petal of the gammadion on metasurface chiral properties at the operating frequencies range of 0.05-0.35 THz.

2. Description of the structures

The unit cell of the structure under investigation is four double truncated ellipses forming four petals of the gammadion, as shown in figure 1. The gammadion petals are made of metallic (PEC) twisted strips width of 7 µm which are located on a silicone (Si) substrate with permittivity of 11.56. The substrate thickness is \( h=150 \) µm, a side of the unit cell is \( d=600 \) µm. The chiral metasurface was designed to operate in the frequency range of 0.1-1 THz.
The ellipse semiaxis $b$ along the y-axis has a fixed length of $150 \mu m$, and the ellipse semiaxis $a$ along the x-axis changes, see figure 1 (b)-(d).

![Figure 1](image.png)

**Figure 1.** (a) Schematic of the chiral metasurface unit cell under study. The ellipse aspect ratio has values of (b) $b/a=2$; (c) $b/a=1$; (d) $b/a=0.5$.

Thus, we obtain three different geometric structures with different chirality properties.

3. **Numerical simulation results**

The virtual experiment was performed by commercial software CST Microwave Studio software based on Finite Integration Technique. In numerical simulation it was used the unit cell boundary conditions in $x$ and $y$ directions and the open boundary conditions in $z$ direction. The ellipticity angle and the azimuth polarization rotation angle are derived using Jones matrix [20] in terms of transmission of the left- and right-handed circularly polarized waves ($T^{++}, T^{--}$) in the frequency range of $0.05 – 0.35$ THz. The peculiar spectra of ellipticity angle for the different ratios of the ellipses semiaxes forming the the gammadion petal on the metasurface are shown in figure 2.
Figure 2. The ellipticity angle of metasurface for the ellipse aspect ratio forming the petal of the gammadion: a) $b/a>1$; b) $b/a=1$; c) $b/a<1$.

As seen from figure 2, there are several especial values of frequency in vicinity of which the sharp changing of polarization properties is observed. The changing of the ellipse aspect ratio (hereinafter referred to as “the ratio”) leads to shifting of the values of these frequencies and changing of the metasurface polarization properties. In figure 2-a) one can see ellipticity angle and azimuth polarization rotation angle for the metasurface with the ratio of $b/a=2$. In this case ellipticity angle values are low (maximal $|\eta|=14$ degrees), but the structure shows giant optical activity at three resonant frequencies. Two of these extremes have positive maxima and negative minima. Such metasurface might be used as vector $E$ rotator. The opposite ratio ($b/a=0.5$) shows a different situation
(figure 2-c). The number of resonant frequencies increased, as well as the values of angle of ellipticity (maximal $|\eta|=39$ degrees). In this case azimuth polarization rotation angle has only positive or negative extremes at the same frequency, unlike the previous metasurface. This design can be used in development of multiband polarizer. The amount of ellipticity angle resonant frequencies in figure 2-b) is between the first and the second cases described above. It can be seen that the ellipticity angle values of the metasurface with circular gammadion are bigger than the ones with elliptical gammadion. The graph with azimuth polarization rotation angle looks like the superposition of such graphs in figure 2-a) and 2-c). So, this metasurface can work not only as elliptical polarizer, but as multiband linear polarization rotator.

4. Conclusions

In this work the influence of the ellipse aspect ratio forming the petal of the gammadion on metasurface chiral properties at the operating frequencies range of 0.05-0.35 THz was studied. Hence, in this paper we demonstrate polarizing properties changes caused by changes of the ellipse aspect ratio. Therefore it is possible to predict the required polarizing properties of metasurface and make an elliptic polarizer or linear polarization rotator, or make one metasurface which can be used as both of them.

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