Twisted Split-ring Chiral Metamaterials for Broadband Circular Dichroism

Ruonan Ji, Shaowei Wang, Xiaoshuang Chen and Wei Lu

National Lab for Infrared Physics, Shanghai Institute of Technical Physics, Chinese Academy of Sciences

Shanghai, China 200083

wangshw@mail.sitp.ac.cn

***Abstract*—In this paper, a kind of twisted split-ring chiral metamaterials is proposed to obtain integratable broadband circle dichroism. With coupling among closely spaced twisted split-rings, a broadband circle dichroism is achieved owning to the combined effect of Bragg resonance and internal resonance.**

Keywords—metamaterial; chirality; circular dichroism

I. INTRODUCTION

Circular dichroism (CD), the different optical response of materials to left-handed (LCP) and right-handed circularly polarized (RCP) excitations, has played an indispensible role in circle polarization control and detection. As CD effect in chiral metamaterials can exceed the corresponding effects in natural chiral materials by many orders of magnitude, recent advances in metamaterials have opened new routes towards integrated circular polarizers with low-profile and larger bandwidths of operation.

Three-dimensional chiral structures such as helices may be used to realize circular polarizers. Though they can obtain broadband circular dichroism [1], the complicated fabrication process greatly limited their applications. Recently, planar structures, such as conjugated gammadion [2], the rotating rosette [3], the twisted cross [4], the U-shaped split-ring resonators (SRR) [5], etc., are propose to realize a similar function. However, the CD effect of all these structures have been restricted to narrow frequency ranges, modest bandwidth increases are usually achieved at the price of integration difficuly.

In this paper, a kind of twisted split-ring chiral metamaterials, which can be realized with multiple electron beam lithography, is proposed to achieve broadband circular dichroism. Coupling among the closely spaced twisted plasmonic metasurfaces may effectively operate as three-dimensional helical structures with broadband bianisotropic optical response.

II. STRUCTURE AND DESIGN

The unit cell of the twisted split-ring chiral metamaterials (TSRCMMs) is shown in Fig. 1. Here, a 4-layer twisted split-ring chiral metamaterials structure is taken for an example. It consists of cascading four identical golden spilt-rings with a separation distance d and a specific rotation angle θ_1 of the second surface compared with the first one. The rings are separated with silicon monoxide spacer. Every golden rings are adherent to the spacer with a 5-nm titanium adhesion layer. The geometry dimension parameters of the spilt-rings are as follow: groove angle θ_2=90°, thickness ta=200 nm, inside radius r_i=364 nm, outside radius r_o=604 nm, separation distance d=235 nm, rotation angle θ_1=120°. The whole structure is fabricated on silicon substrate with a period of p_x=p_y=1200 nm. The simulation is performed by commercial software (Lumerical FDTD Solutions), which is based on the Finite Difference Time Domain (FDTD) method. The dielectric properties of gold and titanium as given by Palik are used.

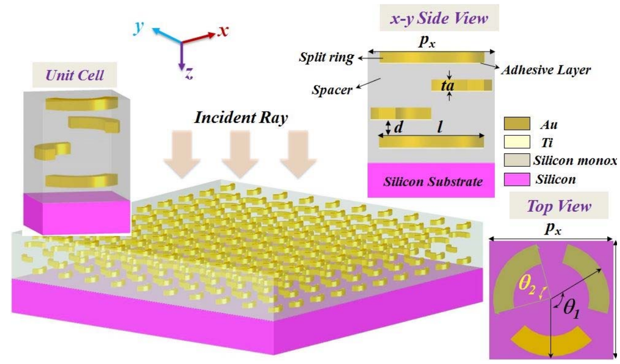


Fig. 1. Schematic of the unit cell for the TSRCMMs structure.

Perfectly match layer (PML) absorbing boundaries are applied in the z direction and periodic boundaries are used for a unit cell in the x-y plane. In the actual simulations, a linearly polarized EM wave with the electric field polarized in the x(y) direction is incident on the TSRCMMs and two linear transmission coefficients are measured, and the transmission coefficients of circular polarization can be expressed as equation (1).

$$T_c=\begin{pmatrix} T_{++} & T_{\pm} \\ T_{m} & T_{--} \end{pmatrix}=\frac{1}{2}\begin{pmatrix} (T_{xx}+T_{yy})+i(T_{xy}-T_{yx}) & (T_{xx}-T_{yy})-i(T_{xy}+T_{yx}) \\ (T_{xx}-T_{yy})+i(T_{xy}+T_{yx}) & (T_{xx}+T_{yy})-i(T_{xy}-T_{yx}) \end{pmatrix} \quad (1)$$

where the subscripts + and − represent the right-handed polarized (RCP) and left-handed polarized (LCP) waves, respectively.

III. Results and Discussions

Fig. 2 shows the transmittance and direction of the surface current for each layer at respective resonant wavelengths. The varies directions of the surface current indicate that the closely spaced twisted split-rings are coupled with different coupling mode, leading to different optical response for LCP and RCP excitations. In other words, circular dichroism is obtained.

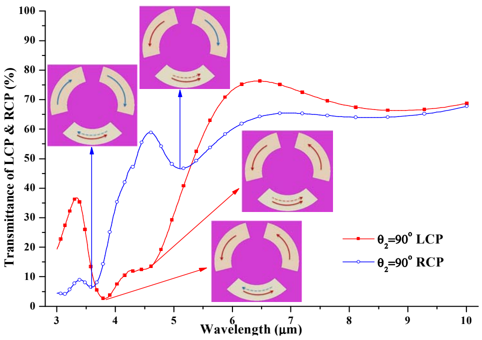


Fig. 2. Normal-incidence LCP and RCP transmittance spectra of the twisted split-ring chiral metamaterials. (Inset figures show the directions of the surface currents on each layer at each resonant frequency, dash lines with arrows for bottom layers and solid lines with arrows for top layers.)

In our work, each split-ring of the TSRCMMs can be treated as a tiny resonant electromagnet induced by the incident light field. By staking split-rings with different split directions, similarly with the U-shaped SRRs, internal resonance resonances due to electric-magnetic dipole coupling will appear but limited to a narrow frequency [5]. While, by adding periodically arranged split-rings, Bragg resonances will appear, and the superposition of the internal and Bragg resonances finally lead to a broad stop band. Thus, one can indicate that by adding more layers, more internal and Bragg resonances may appear to achieve a wider circular dichroism range.

The influence of the groove angle θ_2 is shown in Fig. 3. No circular dichorism is observed with groove angle of 30^o due to the internal resonance between layers are negligible. And the stop bands for LCP and RCP both get wider as groove angle increasing. To clarify the physics behind, the resonant wavelengths of the four resonance modes in Fig. 2 are listed in Table 1. As one can see, the resonant wavelength for a certain resonance red-shift with the increase of groove angle. The whole structure can be equivalent to a LC circuit [6]. Each split-ring and the capacitive coupling of the rings contribute to the inductance and capacity, respectively. Increasing of equivalent inductance and capacity causing by enlarging of the overlapped areas may finally leading to a longer resonant wavelength as Table 1 shows.

IV. Summary and Conclusions

In this paper, a kind of twisted split-ring chiral metamaterials, which can be realized with multiple electron beam lithography, is proposed to obtain integratable broadband circle dichroism structures. With coupling among closely spaced twisted split-rings, a broadband circle dichroism is achieved owning to the combined effects of Bragg resonance and internal resonance.

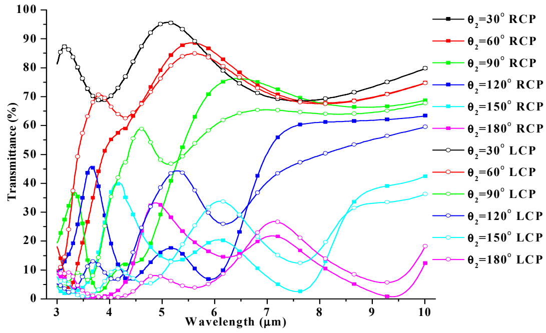
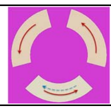
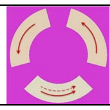
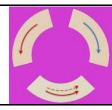
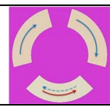


Fig. 3. Normal-incident transmittance of the TSRCMMs with different groove angle θ_2.

TABLE I. Corresponding resonant wavelength of TSRCMMs with different groove angle for resonance mode in Fig. 2

Directions of Surface Currents				
$\theta_2=60^o$	\	3.25 μm	\	4.30 μm
$\theta_2=90^o$	3.81 μm	4.32 μm	3.59 μm	5.13 μm
$\theta_2=120^o$	4.36 μm	5.79 μm	4.07 μm	6.19 μm
$\theta_2=150^o$	5.25 μm	7.58 μm	4.69 μm	7.58 μm
$\theta_2=180^o$	6.22 μm	9.35 μm	5.60 μm	9.35 μm

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