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# Ultra-broad band diode-like asymmetric transmission of linearly polarized waves based on the three-layered chiral structure

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ABSTRACT

We propose a kind of three-layered metamaterial which can realize ultra-broad band diode-like asymmetric transmission (AT) of linearly polarized waves and almost 90° cross-polarization rotation in the optical region. Numerical results reveal that the AT amplitude enables to achieve the maximum of 0.97 and surpass 0.8 ranging from 124 to 244 THz for linearly polarized waves. Two layers of sub-wavelength gratings and a split-ring resonator in the middle of the two dielectric substrates form the three-layered structure. We believe that our work will offer a new opportunity in many optical applications of optical devices such as polarization rotators and diode-like devices.



## 1. Introduction

During the past decade, as a kind of artificial material, the chiral metamaterial (CMM) has attracted much attention owing to its extraordinary electromagnetic (EM) characteristics, such as negative refractive index [1–3], invisibility cloaks [4,5], perfect EM wave absorbing [6–8] and circular dichroism [9,10]. Due to its unique effect with CMM, the asymmetric transmission (AT) plays an important role in wide optical applications and information processing. Since the planar chirality effect, the incident polarized wave converts into one of opposite handedness, leading to the AT for the opposite directions of propagation [11]. Therefore, it is similar to electronic diode effect that the electric current is allowed to transmit in one direction while it is blocked in the opposite direction [12]. The phenomenon of AT of linear or circular polarization waves is able to be found application in many EM devices. Recently, an increasing number of complicated structures have been proposed to acquire AT effect for linearly or circularly polarized waves in microwave [13–17], terahertz [18–21] and optical frequency regions [22–25]. In 2010, a three-dimensional chiral structure was reported by Menzel et al. [23], which could obtain AT for both linearly and circularly polarized waves in optical frequency region. However, the AT parameter was less than 0.25. In 2014, Song et al. [26] proposed a three-layered CMM with broadband high-efficiency and multi-band cross-polarization conversion for linearly polarized waves, but the AT effect was only achieved in microwave region. Meanwhile, Xu et al. [27] presented a kind of bi-layered structure to achieve AT effect for linearly polarized waves, but the AT parameter was less than 0.6. In 2015, Liu et al. [28] investigated a chiral bi-layered structure with broadband high-efficiency transmission for linearly polarized waves, however the frequency range was less than 30 THz in the condition that AT parameter was

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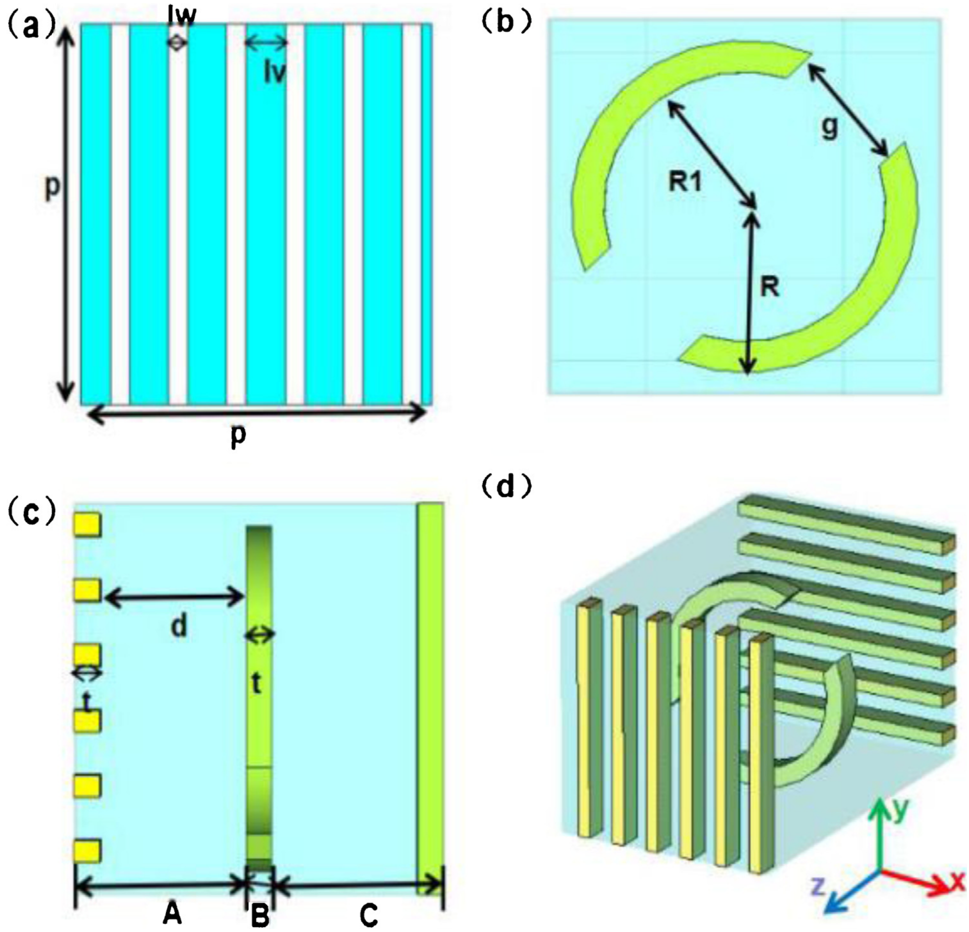


**Fig. 1.** Schematic of the unit cell of the chiral structure. (a) Top layer. (b) Middle layer. (c) The ABC model and thickness of metal and substrate. (d) Perspective view of the structure.

larger than 0.8. As a result, high magnitude and broad bandwidth of asymmetric transmission for linearly polarized waves are still highly desirable [29].

In 2016, a kind of multi-layered CMM which comprises of a split-ring resonator in the middle of two layers dielectric substrates has been reported in microwave frequency region by Xu et al. [30]. In this paper, similar structure is used to obtain ultra-broad band AT effect for the linearly polarized waves in optical region. We find that AT parameter reach a maximum value of 0.97 and it is more than 0.8 ranging from 124 to 244 THz. The high magnitude and broad bandwidth of AT for linear polarization in optical region has not been obtained simultaneously in previous work. Because of these properties of the AT effect, we believe that our work will offer a new opportunity in many optical applications, such as diode-like devices and polarization rotators.

## 2. Designed structure and basic theory

Fig. 1 depicts the unit cell of the proposed structure. For convenience, the chiral structure was decomposed into three components: layer A, layer B and layer C, as shown in Fig. 1(c). Layer A is constructed by a substrate and a sub-wavelength grating paralleling to y-axis which is transmittable to x-polarized wave and meanwhile blocking y-polarized wave. A double-split ring embedded in the substrate constitutes layer B. Layer C is the same as the layer A except that the grating is parallel to x-axis. Thus, it is transparent to y-polarized wave and blocking x-polarized wave. We achieve the simulation results of the chiral structure based on finite integration technology (FIT) method. In our simulations, we adopt silica with the relative permittivity 2.25 as dielectric substrate. And we use Drude model to describe the metallic layers. Consequently, the effective permittivity of silver is given by $\varepsilon(\omega) = 1 - \omega_p^2/\omega(\omega + i\omega_c)$ [31], where $\omega_p$ and $\omega_c$ is the plasma frequency and the collision frequency ($\omega_p = 2\pi \times 2.175 \times 10^{15} s^{-1}$ and $\omega_c = 2\pi \times 6.5 \times 10^{12} s^{-1}$).

The optimized geometric parameters of the structure are as follows: p = 360 nm, l w = 20 nm, l v = 30 nm, R = 160 nm, R1 = 130 nm, g = 120 nm, d = 230 nm. The thickness of every metallic layer is 40 nm.