Broadband terahertz reflective linear polarization convertor

Yong Zhi Cheng[1, 2], Withawat Withayachumnankul[1,3], Aditi Upadhyay[3], Daniel Headland[1], Yan Nie[2], Rong Zhou Gong[2], Madhu Bhaskaran[3], Sharath Sriram[3], and Derek Abbott[1]
[1]School of Electrical and Electronic Engineering, The University of Adelaide, Adelaide, South Australia, 5005, Australia
[2]School of Optical and Electronic Information, Huazhong University of Science and Technology, Wuhan, 430074, China
[3]Functional Materials and Microsystems Research Group, RMIT University, Melbourne, VIC 3001, Australia

***Abstract*—A broadband terahertz reflective linear polarization convertor is proposed. The structure is composed of a metallic disk and split-ring resonators in proximity to a ground plane. It is found that the structure exhibits three neighboring resonances, from which the linear polarization of incident light can be rotated to its orthogonal counterpart after reflection. Both simulated and experimental results exhibit that the polarization conversion ratio is greater than 80% in the range of 0.53–1.34 THz, equivalent to 82.1% relative bandwidth. This presented design for enhancing efficiency of polarization conversion has potential applications in the area of terahertz spectroscopy, imaging, and communications.**

I. INTRODUCTION

Polarization is an important and also basic characteristic of electromagnetic (EM) waves and has been utilized in many areas, including imaging and communications [1]. Thus, effective manipulation of the EM wave polarization is highly desirable, and has been an important research topic for long time. Conventional methods for polarization manipulation, such as gratings, dichroic crystals and Faraday effects, usually require a relatively long propagation distance to obtain enough phase accumulation despite their limited performance, availability, and controllability. Metamaterials as artificial media can offer benefits beyond conventional materials. They may be employed as an alternative to the aforementioned structures for manipulating polarization [2-4].

Recently, several polarization converters or rotators have been proposed and demonstrated through specific microstructures design, such as anisotropic metamaterials [2-5] and asymmetric chiral metamaterials [6-9]. Compared with the traditional polarization manipulation devices, these metamaterial-based polarization rotators or convertors have such advantages as flat profile, high conversion efficiency, and scalability. However, in nearly all of the existing polarization convertors, the polarization states are manipulated in the transmission mode [6-13]. Comparatively, a limited number of polarization converters operate in the reflection mode [2,4]. To extend the functionality, broadband reflective linear polarization conversion with high performance is still highly desirable, particularly in the terahertz region. Here, we demonstrate a broadband terahertz reflective linear polarization convertor by numerical simulations and experiments.

A schematic of the proposed reflective linear polarization convertor is shown in Fig. 1. The convertor consists of a metallic disk and split-ring resonators placed near to the ground plane. As shown in Fig. 1(a), from the front to the back, the unit-cell structure is composed of a patterned metal layer, a polydimethylsiloxane (PDMS) substrate, and a ground plane. Figure 1(b) illustrates an optimal design of the top layer. The structure is periodic along the x and y axes with periods p_x and p_y of 110 µm, which do not invoke diffraction at normal incidence for frequencies below 2.7 THz. This two-layer design forms a Fabry-Pérot–like cavity, leading to multi-reflection polarization couplings [5].

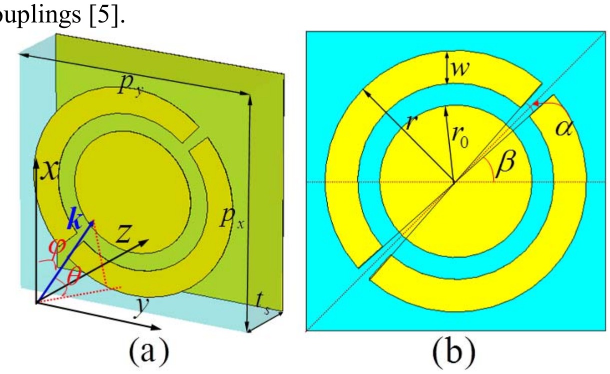

Fig.1. Diagram for a unit cell of the designed structure (a) perspective view (b) front view. The geometry parameters are given as: $p_x = p_y =$ 110 µm, r = 48 µm, w = 12 µm, r_0 = 28 µm, t_s = 30 µm, α = 6.8°, β = 41.6°, and t_m = 0.2 µm.

II. RESULTS

In order to verify the linear polarization conversion, numerical simulations were performed with the frequency domain solver in CST Microwave Studio based on finite element method (FEM). In simulation, the relative permittivity and loss tangent of PDMS, determined experimentally, are 3 and 0.06, respectively [14]. The surface impedance for gold is obtained from the Drude model [15]. The micro-fabrication of photolithography was undertaken to realize the structures in Figs. 1(a,b) [15]. Then, reflection-mode terahertz time-domain spectroscopy (THz-TDS) is performed on the sample for the normal incidence. We define $r_{xx} = E_x^r / E_x^i$, $r_{yx} = E_y^r / E_x^i$, $r_{xy} = E_x^r / E_y^i$, and $r_{yy} = E_y^r / E_y^i$ as the reflection coefficients for the co- and cross-polarization. The superscripts i and r denote the incident and reflected terahertz wave, respectively. The subscripts x and y indicate the polarization directions, corresponding to TM and TE modes, respectively. Due to the structural symmetry, we need to consider only the incident y-polarized waves, and the reflection coefficients r_{yy} and r_{xy} in the simulation and experiment for normal incidence.

Figures 2(a,b) show the simulated and measured magnitude of the reflection coefficients, and the polarization conversion ratio (PCR) for the normal incidence terahertz wave with y-polarization. It can be seen that the numerical and experimental results are in reasonable agreement, and the discrepancy is likely caused by tolerances in fabrication and measurement. From the simulation results of Fig. 2(a), there exist three resonances: f_1 = 0.63 THz, f_2 = 0.91 THz, and f_3 = 1.28 THz, where the magnitude of the co-polarization reflection coefficients reach minimal values of about 0.14, 0.06 and 0.14, respectively. It should be noted that the first resonance from the measurement is much broader than that in the simulation. This effect suggests that the first two resoances are combined into a single resonance. Both the simulated and experimental magnitude of the cross-polarized reflection coeffi cient is greater than 50% from 0.53 to 1.34 THz, while the co-polarized reflection coefficient is less than 30% on average. The results suggest that the resonances underlie the observed polarization rotation.

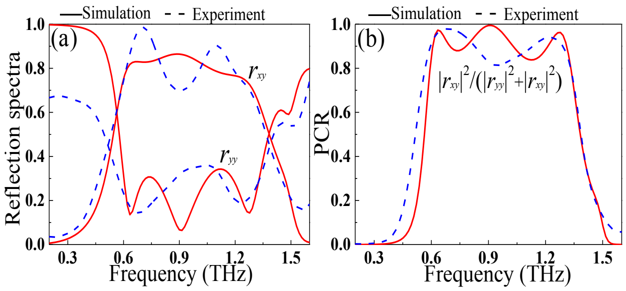

Fig.2. Simulated and experimental results for normal incidence: (a) The magnitude of reflection coefficients r_{yy} and r_{xy}; (b) Polarization conversion ratio (PCR).

The polarization conversion ratio (PCR) is defined as $\mathrm{PCR} = r_{xy}^2 / (r_{yy}^2 + r_{xy}^2)$ [2]. It is shown that from 0.56 to 1.34 THz, the PCR is always above 0.80 and reaches 0.96 at resonance frequencies. The results demonstrate the capability of linear polarization rotation by 90° with high polarization purity over a broad bandwidth. The high polarization conversion efficiency is mainly arising from an overlap of Fabry-Pérot reflections, where the cross-polarization component is enhanced while the co-polarization component is largely suppressed in the total reflected fields [5].

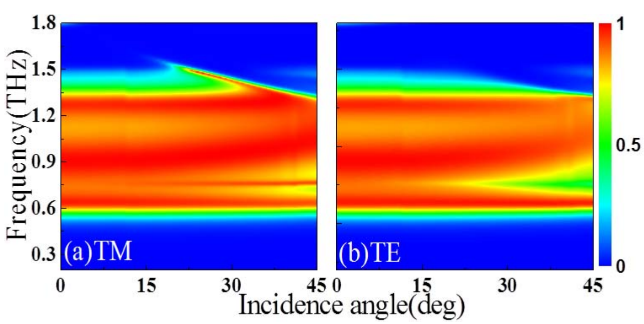

Fig. 3. The simulated PCR as a function of incidence angle θ. (a) TM polarization. (b) TE polarization.

We also consider the angular dependence of the proposed polarization convertor. The numerically resolved PCR for both the TM and TE polarizations are depicted in Fig. 3. For the TM wave shown in Fig. 3(a), the polarization conversion performance is minimally affected with an increasing incidence angle up to 45°. For the case of TE polarization in Fig. 3(b), the polarization conversion performance is maintained up to 30°. Beyond 30°, the polarization conversion starts to degrade because the incident magnetic field decreases rapidly to zero and can no longer efficiently excite the magnetic dipole with an increase in the incidence angle.

III. Summary

We experimentally demonstrated the broadband reflective linear polarization convertor at terahertz frequencies. The results indicate that the incident linearly polarized beam can be converted into its orthogonal polarization counterpart up on reflection. The polarization conversion efficiency is greater than 80% in the frequency range of 0.53–1.34 THz. Additional numerical simulations revealed that this broadband and high efficiency performance can be sustained up to the incidence angle of 30°. The presented design can be used in terahertz imaging and communications.

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