Metamaterial Absorber and Polarization Transformer Based on V-shape Resonator

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***Abstract*-A metamaterial (MM) resonator composed of double V-shape metal wires shows the different manipulations of the transmission and reflection. Parametric studies on the MM reveal that it can work as dual-direction absorber or polarization transformer based on the electric and magnetic resonance between the metal layers. The investigation shows that the absorption of MM resonator is 95.3% at 12.1GHz; and the MM resonator can turn vertical polarized EM waves into horizontal polarized EM waves with polarization conversion ratio (PCR) of 78% at 10.2 GHz. The potential application for microwave dual-directional ideal absorbing and polarization transformation are discussed respectively.**

I. INTRODUCTION

Since their inception in 2001 [1], metamaterials (MMs) have ushered in a new era of electromagnetism. These composite MMs have electromagnetic properties transcending those naturally-occurring media, such as negative refractive index [1-3], invisibility cloaks [4-6], super lens [7-8], perfect electromagnetic (EM) wave absorber [9], and so on. The fundamental purpose of MMs is to realize the manipulation of EM wave, such as the MM absorbers, polarization transformers, Electromagnetically Induced Transparency (ETI) MMs and Negative Refractive Index (NRI) MMs. MM absorber, as one of the most important applications, has been investigated since 2008 [9]. Since then, MM absorbers have progressed significantly with designs shown across the electromagnetic spectrum, from microwave to optical spectrum [9-17]. Recently, dual-directional MM absorbers have been investigated as an available MM, but the disadvantages of the MM absorbers are that the polarization status is sensitive and the structure is bulky [12, 18]. Polarization transformer is another important application in many areas, such as antennas, astronavigation, and communication [19-21]. Thus, it is highly desirable to efficiently control the polarization of EM waves [22]. One of the most efficient methods is the asymmetric transmission (AT) [23-24].

In this paper, a double V-shape MM resonator is designed, which consists of metal layers separated by the substrate (FR-4). The dual-directional MM absorber and the linear polarization transformer can be obtained by taking the advantage of the arrangement of the V-shape gap direction. Numerical simulation shows that the absorption of the MM absorber is perfect at dual-direction. Further investigation shows that the absorber performs insensitive under different polarized EM waves. In addition, the resonant character is verified that only dielectric losses affect the optimized absorbers' overall performance. Then a polarization transformer is investigated by rotating the V-shape's direction. The MM transformer can convert vertical polarization wave into horizontal polarization wave based on AT, and the polarization conversion ratio (PCR) reach 78% at 10.2 GHz. The MM resonator is tunable so that realize the manipulation of EM wave [24].

II. STRUCTURE DESIGN

A schematic layout of the implemented unit cell of the MM, including all geometrical parameters, is shown in Fig. 1. The model consists of double V-shape copper wires on the FR-4 dielectric substrate. The conductivity of the copper is $\sigma=5.8\times10^{7}$S/m and the permittivity of the FR-4 is $\varepsilon=4.9+i0.025$.The inner gap of the inner V-shape a=3.5mm; the width of the metal wire $w_1=w_2$=0.5mm, and the thickness is t=0.04mm, the gap between the two V-shapes g=0.3mm, the arm of the V-shape L_1=4.6mm, L_2=6.35mm.

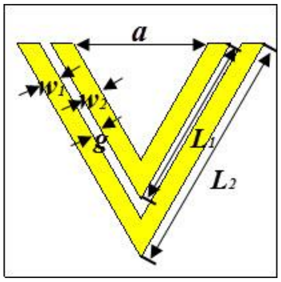


Figure 1. The schematic of the matamaterial resonator consists of double V-shape copper wires.

III. DEMONSTRATION OF DUAL-DIREACTION METAMATERIAL ABSOBER

To obtain dual-directional absorbing, the double V-shape is arranged on both of the dielectric layer sides. In consideration of the polarization factor, the gap orientation is open to four perpendicular directions to each other, as shown in Fig. 2. The dielectrics b_1=13mm, the distance of V-shape peak d_1=0.5mm, d_2=0.75mm, and the thickness of dielectric substrate is 1.2mm, Computational simulation install periodic boundary as unit cell on *x*-*y* plane. Along *z* axis is the EM wave vector **k**.

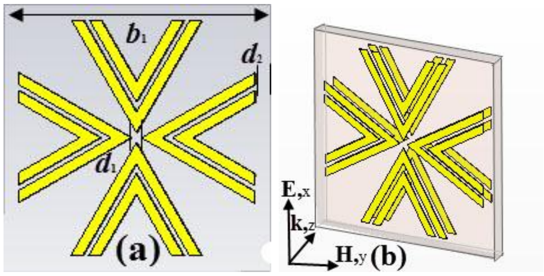


Figure 2. (a) The planar sketch of the MM absorber. (b) The 3-D model.

Based on finite difference time domain method (FDTD), we use CST simulating the S-parameter of the reflection and transmission. The results are shown in Fig. 3. Comparing (a) with (b), it is seen clearly that the absorbing performances are totally coincident when the incident waves propagate from +*z* and –*z* direction. The resonant band occurs at 12.1GHz, and the absorption peak reach 95.3%. Then the different polarized EM wave is simulated, which is shown in Fig. 4. The simulation result shows that the MM absorber is insensitive to different polarization status.

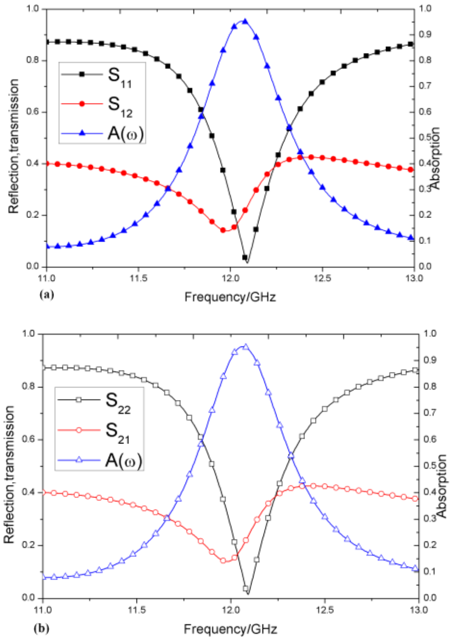


Figure 3. Simulated reflection, transmission and absorption curve of the V-shape resonator. (a) +*z* direction propagation EM waves. (b) -*z* direction propagation EM waves.

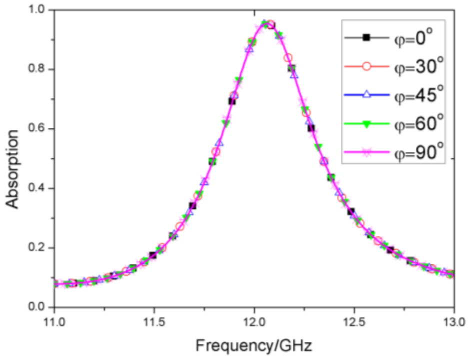


Figure 4. Absorption curves of the MM absorber at different linear polarization angles (φ).

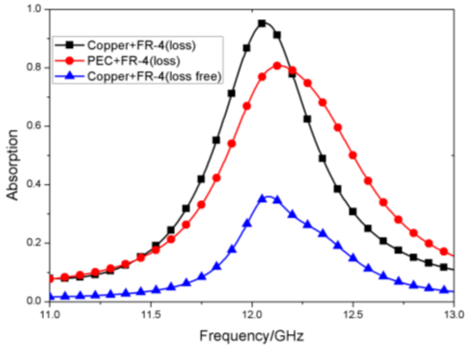
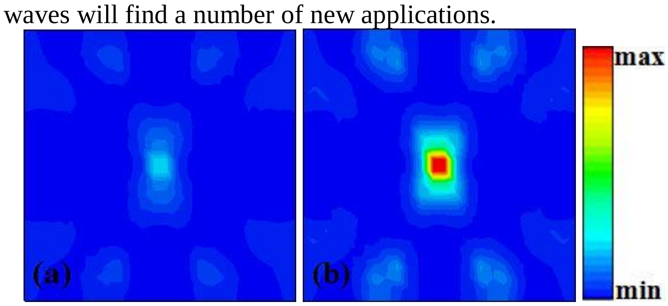


Figure 5. Investigate the physical origin by using different combination of metal and substrate.

To reveal the physical original mechanism of the absorption in the MM absorber, the connection between the metal and substrate are investigated. We use loss free dielectric substrate and loss substrate (FR-4) to simulation, the result is shown in Fig. 5. When Copper loads loss free FR-4, the maximum absorption is 35.9%; PEC and loss FR-4, the absorption peak is 80.7%; and Copper match loss FR-4, the absorption is 95.3%. That means the energy loss origin from the loss dielectric. Then the electronic and magnetic energy distribution on the substrate is displayed, as shown in Fig. 6. Note that when the EM wave illuminates the absorber along +*z* axis (see Figure 2), the electronic and magnetic energy concentrate on the back of the substrate, mainly on the wedge and the arms of the V-shape. That is completely different from the normal resonant absorber. The transmitted power concentration increases considerably on the back, mimicking the angle-based sub-wavelength scale focusing of EM energy. Such a resultant ability to focus EM waves will find a number of new applications.



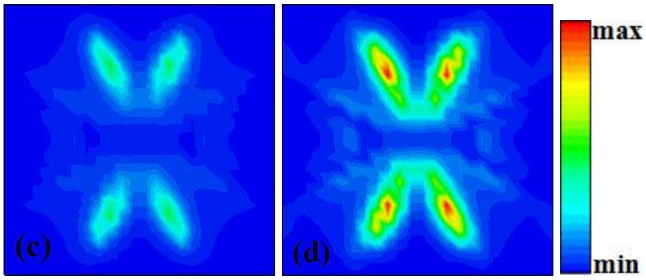


Figure 6. The energy distribution on the substrate, EM waves propagate along +*z* axis. (a) Electric energy on the front substrate.(b) Electric energy on the back substrate.(c) Magnetic energy on the front substrate. (d) Magnetic energy on the back substrate.

We demonstrate and simulate a double V-shape dual-directional absorber which was utilized combination method, the absorptivity is 95.3% at 12.1 GHz, and the absorber is insensitive to polarization status. According to the energy loss distribution, we find that the energy is backward concentration on dielectric substrate when the EM wave propagates along +*z* axis. That is to say, we may use the MM absorber to realize energy control. Furthermore, the model can also be applied on microwave absorbing materials, EM wave clacking and some other related fields.

IV. DEMONSTRATION OF POLARIZATION TRANSFORMER

We realign the double V-shape resonator to make the V-shape gap twisting 90° which is shown in Fig. 7. Every unit holds a quarter of the spatial position, shown in Fig. 7 (a), the dielectric width is b_2=14mm and thickness is 1.0mm, d_3=0.75mm, d_4=0.65mm, d_5=0.325mm. Fig. 7 (b) shows the 3-D polarization transformer model. The computational simulation has been performed based on the standard time domain (FDTD) method by using CST Microwave Studio’s Frequency Domain Solver, installing periodic boundary as unit cell on *x*-*y* plane. Along +*z* axis is the linear polarized EM wave vector ***k***.

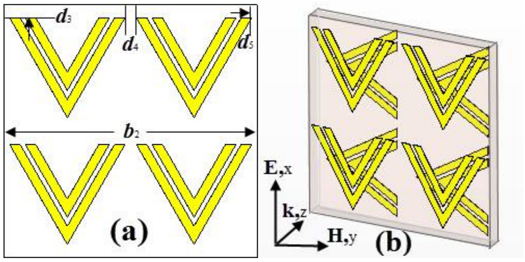


Figure 7. The model of linear polarization transformer. (a) The planar sketch. (b) The 3-D model.

Based on the simulation, the reflection and transmission coefficients are shown in Fig. 8. When the linear polarized EM waves propagate along the +*z* direction (see Fig. 7), the co-polarization transmission t_{xx} and t_{yy} are always remain same, while the cross-polarization transmission components t_{xy} and t_{yx} differ significantly across the whole frequency range. That means there existing a strong asymmetric transmission of the linear polarized wave. The amplitudes for the co-polarization transmission reduce to a minimum of about 0.14 at 9.9 GHz. One can clearly observe that the amplitude of the cross-polarization transmission t_{xy} achieves a maximum of 0.6 in the simulation around the resonance frequency of 10.2 GHz, while t_{yx} is stay below 0.1 in the entire frequency range.

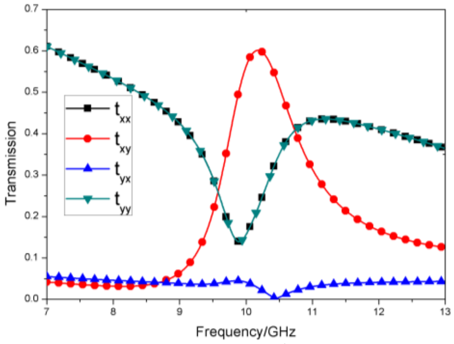


Figure 8. Simulated transmission spectra of the polarization transformer.

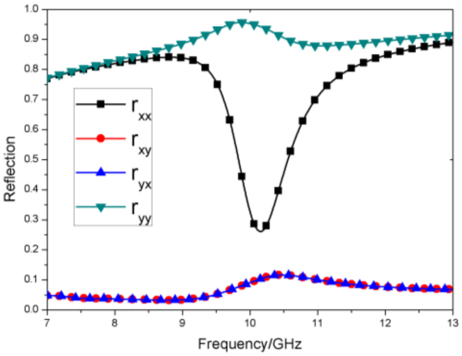


Figure 9. Simulated reflection spectra of the polarization transformer.

Fig.9 shows the simulation reflection for propagation along +*z* direction (see Fig. 7); the cross-polarization reflection r_{xy} and r_{yx} stay small and below 0.12 in the entire frequency range. While the co-polarization r_{xx} reduces to a minimum of about 0.26 at the frequency 10.2 GHz, r_{yy} is near unity across the whole frequency range. These results of the reflection further verify that the incident x-polarization wave will be forbidden to transmit for propagation along the +*z* direction. That is, the coupling of the front and back double V-shape each other is very low for this polarization, and nearly without magnetic coupling, resulting in a high reflectivity, and no polarization transformation can be observed.

We demonstrate the double V-shape resonator whose direction’s permutation is not uniform may obtain a linear polarization transformer. The transmission and reflection spectra show that the resonator emerges the phenomenon of asymmetric transmission at about 10.2 GHz. The *x*-polarization (vertical polarization) wave is transformed to *y*-polarization (horizontal polarization) wave. The transmission spectra reach a maximum 0.6 and the PCR is 78%. Such a design may find potential application in optical isolators, microwave wave plates, or other EM control devices.

V. CONCLUSION

In conclusion, we demonstrate a double V-shape MM resonator, which can work as microwave absorber when the front and back V-shape direction is coincident. While the back

V-shape gap relative to the front is transformed 90°, the resonator is a 90° linear polarization transformer. As a MM absorber, the absorption peak is 95.3% at 12.1 GHz, and the absorber is polarization insensitive to the incident EM microwave. As a polarization transformer, the vertical polarization wave can be transformed to horizontal polarization. This design may apply on dual-directional invisibility technology, radar absorbing materials, optical isolator and other EM control devices because of the tunable property.

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