Design of Metamaterial Absorber based on Flexible Substrate

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ABSTRACT: Artificially engineered metamaterials have enabled the creation of electromagnetic (EM) materials with properties not found in nature. This paper presents an EM wave absorbing structure of flexible substrate based on metamaterials, which can resonance in the microwave frequency, and also it has wide broadband polarization and strongly angle-insensitive absorption characteristics. By exploiting the scalability property of metamaterials, the operational bandwidth of the design can be drastically improved by placing unit cells with properly scaled resonators adjacent to each other. Simulations show that the metamaterial abosorber has dual band absorption up to 99.9% in the regime of 0.5-3THz with different incident angles.
KEYWORD: metamaterials; absorber; resonance; bandwidth; angle-insensitive

1 INSTRUCTION

Metamaterial is one of the most attractive fields in recent years. Mostly, metamaterials are prepared by artificially periodic structure, which results in the materals' permittivity ε and permeability μ to be both negative or one. Left-handed materials (LHM) is a class of artificial composite materials with unusual electromagnetic properties, including negative refractive index [1] ,inverted Doppler effect, and inverted Cherenkov radiation. With the above features, artificial electromagnetic metamaterials have been applied in all aspects of antennas, sensors, stealth cloak, absorbing and so on [2-5]. An ideal metamaterials absorber should be broadband and independent to polarization with exhibiting a near unity absorbance, the last of which is an intrinsic characteristic of absorbers. However, most existing planar metamaterials absorbers can only operate in a narrow range of frequencies [6]. Some absorbers are even sensitive to the polarization of incident wave due to their asymmetric designs. The most widely used absorbers is the wedge-shaped electromagnetic absorbing device [7-8]. However, since this kind of pyramidal absorber is easy to be damaged physically and it has bulky dimension, the absorber is difficult to be integrated with surface of vehicles. In this article, a cross-gap structured metamaterial absorber has been presented. Simulations show that it is of insensitive polarization and of dual-band absorption at frequencies range of 0.5-3THz.

2 FUNDAMENTAL THEORY

The principle of the absorber designed is that the impendance Z of the material must be matching with the impendance of free space. When reflectivity and transmission are calculated, respectively, the absorption is defined as A(ω)=1-R(ω)-T(ω). With the incident electromagnetic wave, there will be electric and magnetic resonance in the metamaterial. The complex permittivity [9] is defined as $\varepsilon=\varepsilon_1+j\varepsilon_2$, where ε_1 is the real part of the complex permittivity, and ε_2 is the imaginary part. Similarly, the complex permeability define as $\mu=\mu_1+j\mu_2$, with μ_1 the real part and μ_2 the imaginary part. Equivalent input impedance of the metamatieals is defined as $z=\sqrt{\mu/\varepsilon}$. The S_{21} are determined by the complex refractive index and effective impedance: $n(\omega)=\sqrt{\mu(\omega)\varepsilon(\omega)}$, $Z=Z_0+Z_i$ as

$$S_{21}^{-1}=\left[\sin(nkd)-\frac{i}{2}(Z+\frac{1}{Z})\cos\theta(nkd)\right]e^{ikd}$$

$$R=\frac{Z_0-Z_i}{Z_0+Z_i}$$

$$Z_0=\sqrt{\frac{\mu_0}{\varepsilon_0}},Z_i=\sqrt{\frac{\mu_i}{\varepsilon_i}}$$

Where d is the thickness of the material, k is the wave number and R is the reflection coefficient. When the impendence Z=1, above equations could be rewritten as

$$S_{21}^{-1} = [\sin(nkd) - i\cos(nkd)]e^{ikd}$$

$$\lim_{n_2 \to \infty} T(\omega) = 0$$

$$R(\omega) = |S_{11}|^2 = 0$$

Therefore, when the impedance is a perfect match, the imaginary part of the complex refractive index material is infinite, the transmission and reflectivity are almost zero, then the maximum absorption of the material reaches 100%.

3 DESIGN AND SIMULATION

Figure 1 shows the structure of the unit cells of designed metamaterial absorber. The absorber consists of two metallic layers with thickness of 200nm were separated by a dielectric spacer. The permittivity of the dielectric spacer is ε=3.5+i0.2. Inside the upper thin metal plate, a cross gap was etched as the electrical resonant structure. The size parameters are listed as the following: L_1=38μm, L_2=34μm, W_1=14μm, W_2=8μm, a=42μm, p=50μm. The thickness of the dielectric substrates spacer between the two thin metal plate is 2.4μm.

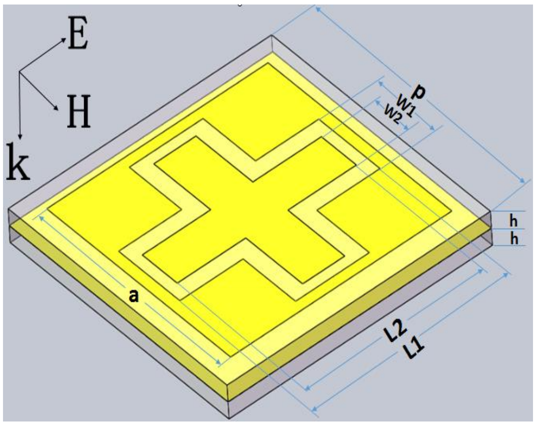

Figure.1 Schematic of the metamaterial Absorber

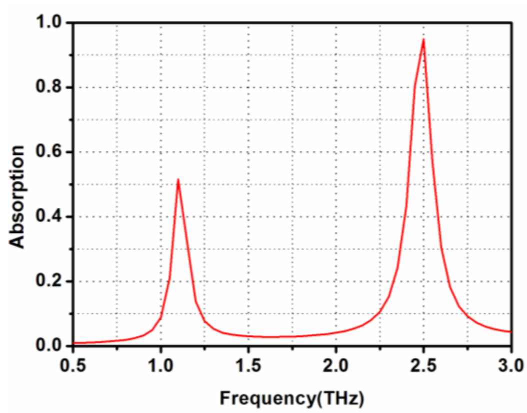

Figure.2 Dependance of the absorption with the frequency when θ=0°

Figure.2 illustrates the reflectance and absorption of the absorber, revealing an absorption peak of 51.56% and 94.91% at 1.1THz and 2.5THz respectively. Incident power absorbed by metamaterial structures generally rely on two aspects: one is by resistive metallic, the other is by lossy dielectric layer. There is no doubt that the complete symmetry of the unit cell along the x direction and y direction ensures the accomplishment of similar absorptive behavior for arbitrary polarizations of the incident wave. From simulations, the transmission parameters S_{21} equals to 0, reflection R(ω)= $|S_{11}|^2$ and the absorption A(ω)=1-R(ω)-T(ω)=1-$|S_{11}|^2$-$|S_{12}|^2$. The electric field distribution was shown in Figure.3 with incident frequency of 2.5 THz. It shows that there was a symmetrically induced current distribution the upper metal plate, which indicates that the current in the opposite direction has the same value. This phenomenon shows that magnetic fields cancel each other and the strong transmittance has appeared. Therefore, the portion of the absorbent structure of the electromagnetic waves is the dielectric substrates.

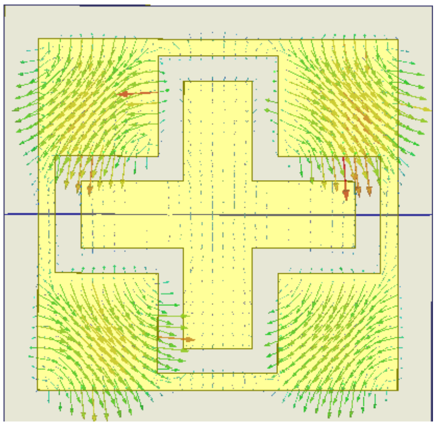

Figure.3 The surface current distribution structure when the TE fed wave in 2.5THz.

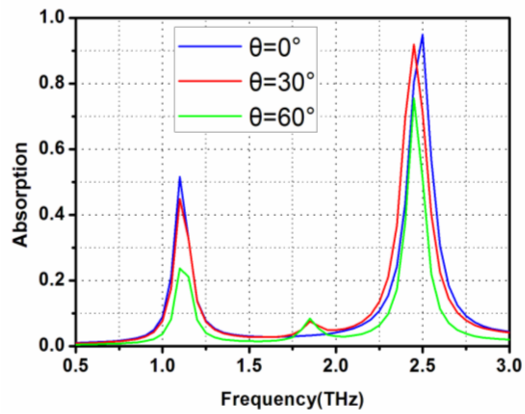

Figure.4 Relationship between absorption of rate and frequency when θ=0°, 30°, 60°respectively.

In this study, the response of the metamaterial absorber to obliquely incident radiation is examined. For the TE case, angle φ is varied, while keeping θ=0°, the absorber shows similar absorption as shown in Figure.4. Conversely, by fixing φ=0°and varying angle θ, dependance of absorption with the frequencies can be seen in Figure 4. The reflectance spectrum reduced with the increase of the incident angle. At the same time, its resonant frequency is almost steady. A strong absorption 94.91% appears near the 2.5THz when θ=0°. Absorption 91.84% appears near the 2.5THz when θ=30°. As shown in the Figure.4, when the electromagnetic wave incident with different angles, there still are strong absorption near the frequency of 2.5THz. Theoretical analysis and simulation results show that the structure can absorb EM wave with a wideangle and is insensitive in polarization.

Absorptions with different thickness of the substrate polymer is shown in Figure.5. It is clearly that absorption has changed when the thickness of the plate varies from 2.6μm to 3.4μm. And the absorption reaches the peak of 99.51% when h=2.6μm.

Figure.6 shows the dependance of the absoption with deferent gap dimensions it founds that the embedded width of the cross structure changes, the low frequency region of the resonance does not change, but the high frequency region of the resonance occur the red shift. Also it shows that the absorption does not change with the increase of the width of the structure embedded in the cross.

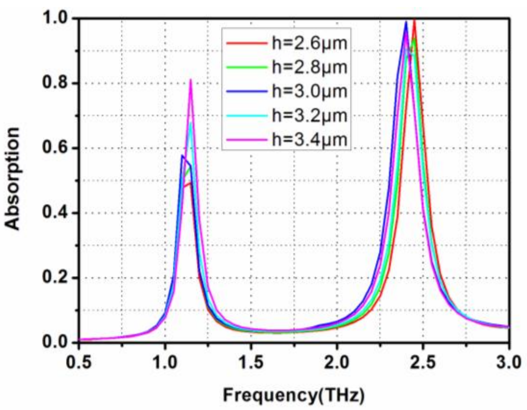

Figure.5 Influence of the thickness of the substrate on the absorption rate.

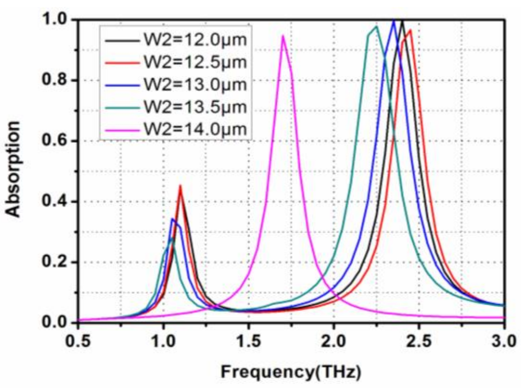

Figure.6 The influence of change of embedded cross width on absorption rate.

4 CONCLUSION

In this artical, metamaterial absorber with structure by etching crossed slot inside a metal plate and full coverage of the bottom plate was designed. We put forward from theory and simulation prove that this structure has a wide-angle strong absorption and polarization-insensitive. Simulations show the metamaterial with an asorption more than 99% with insensitive polarization at 2.5THz. These broadband metamaterial absorbers maybe have potential applications, such as THz modulators and sensors.

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