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Study on the properties of the two-dimensional curved surface metamaterial

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ABSTRACT

Metamaterials become a breakthrough technology due to their potential applications. We numerically investigate the properties of the two-dimensional curved surface metamaterial in the microwave regime. Unlike one-dimensional planar metamaterial, some novel properties are stimulated in the designed two-dimensional curved surface metamaterial. The reflected wave is transformed into its orthogonal polarization wave in addition to the absorbing components for normal linearly polarized electromagnetic wave incidence. The polarization conversion ratio and absorption are discussed detailly under different oblique incident conditions both in transverse electric wave and transverse magnetic wave. The reflections are stable for transverse magnetic wave while changing obviously for transverse electric wave when the incident angle changes from 0° to 60°. The tendency of reflections is almost consistent when the polarization angle changes from 0° to 45° under normal incidence. We also discuss the influences of the geometric parameters on the properties of the two-dimensional curved surface metamaterial. The designed two-dimensional curved surface metamaterial can be a very potential candidate for the radar scattering section reduction and electromagnetic stealth.

1. Introduction

The research of metamaterials(MMs) has experienced a rapid development and is still a hot spot due to its unique properties not existed in natural materials [1–3], such as negative refraction [4,5], invisible cloaking [6,7], antennas [8,9], filters [10,11], perfect absorbers and so on [12–14]. Metamaterial absorber, as one of the most important branches for MMs, can be used in various applications, such as wireless power transfer and harvesting [15,16], sensors [17,18], solar cells and stealth [19,20], and all kinds of single-band, multi-band and broadband absorbers based on planar metamaterials have been investigated in many literatures [21–25]. Except for perfect absorbers on planar surfaces, perfect absorbers integrated onto curved surfaces such as cylinders or even spheres are designed and fabricated [26,27]. The applications include the suppression of spurious back-scattered light and form an optical black hole. The challenge of the design is that even under normal incidence, different areas of the unit cell experience different oblique incident angles. On the other hand, polarization of electromagnetic (EM) waves is one of the most important characteristics which is also widely used in many applications including antenna systems and RCS reduction [28,29]. Researchers have made great contributions to manipulate the polarization states using planar chiral and anisotropic metamaterials ranging from microwave to optical frequencies [30–34]. In addition, ultra-thin chiral metamaterial absorber also has been designed with high selectively absorbing character for LCP wave, but has the RCP wave transmitted directly through [35,36]. However, in the previous works, MM-based absorbers and polarization converters are usually designed separately, never merge these two properties together in the same metamaterial. The practical problem of partial reflection and partial absorption of the incident wave cannot be solved using existed MM-based absorbers and converters.

In this paper, we present a 2D CSM with the geometrical structure defined by a sinusoidal function, and the structure can be tailored with the amplitude and period of the function. The simulation is carried out under different incident angles and different polarization angles. Different from the planar structures, both polarization conversion and absorption are achieved by using the designed CSM. The reflected wave can be converted to the orthogonal-polarization state in addition to the

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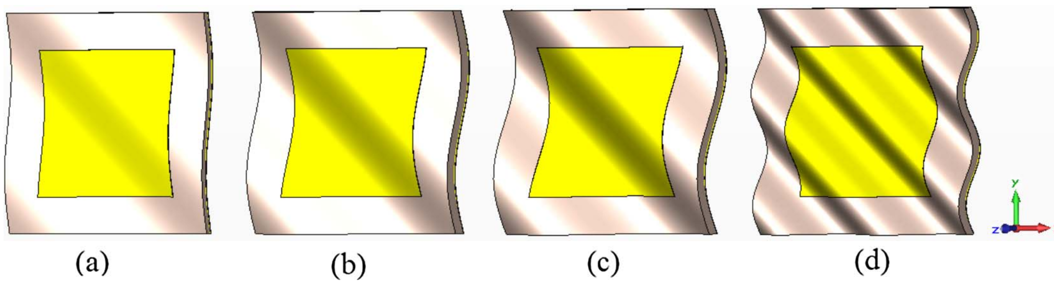

Fig. 1. Schematics of the CSM with different parameters: (a) model 1, (b) model 2, (c) model 3, and (d) model 4.

Table 1
The parameters of four typical geometric models.

Geometric models	A	B	L (mm)	W (mm)	t (mm)
1	0.5	6	12	8	0.5
2	1	6	12	8	1
3	1.5	6	12	8	1
4	1	3	12	8	1

absorbing components for normal and oblique incidence electromagnetic wave. The reflection character of four typical geometric models is simulated and discussed in detail in this paper, the results provide an important reference for designing the multiple functional metamaterials.

2. Design and simulation

The unit cell of the 2D CSM is composed of two metallic layers with a substrate of FR4 between them. The top layer is a square metallic patch projected to the substrate and the bottom layer is a continuous metallic layer attached to the substrate. The two metallic layers are all made of copper with thickness of 0.035 mm. The substrate has a relative permittivity $\varepsilon_r = 4.4$ and loss tangent $\tan\delta = 0.025$ with the thickness represented by t. The curved structure is defined by a function $f(x,y) = A\sin(\pi(x+y)/B)$, where A represents the fluctuation of the structure and B determines the period of the function. The dimensions of the unit cell and the square patch are $L \times L$ and $W \times W$, respectively. The schematics of four typical geometric models are shown in Fig. 1, respectively. The corresponding parameters are listed in Table 1.

Simulations are performed using the CST Microwave Studio software based on the finite integration method. A single unit cell is used with periodic boundary conditions along the x and y directions, and absorbing boundary conditions along the z direction. In Fig. 2, coordinate graphs are illustrated to give a clear representation of the incidence angle θ and the polarization angle φ. When the incident angle θ changes, for TM mode, the magnetic field is always vertical to the plane formed by the incident wave vector and the electrical field; for TE mode, the electrical field is always vertical to the plane formed by the

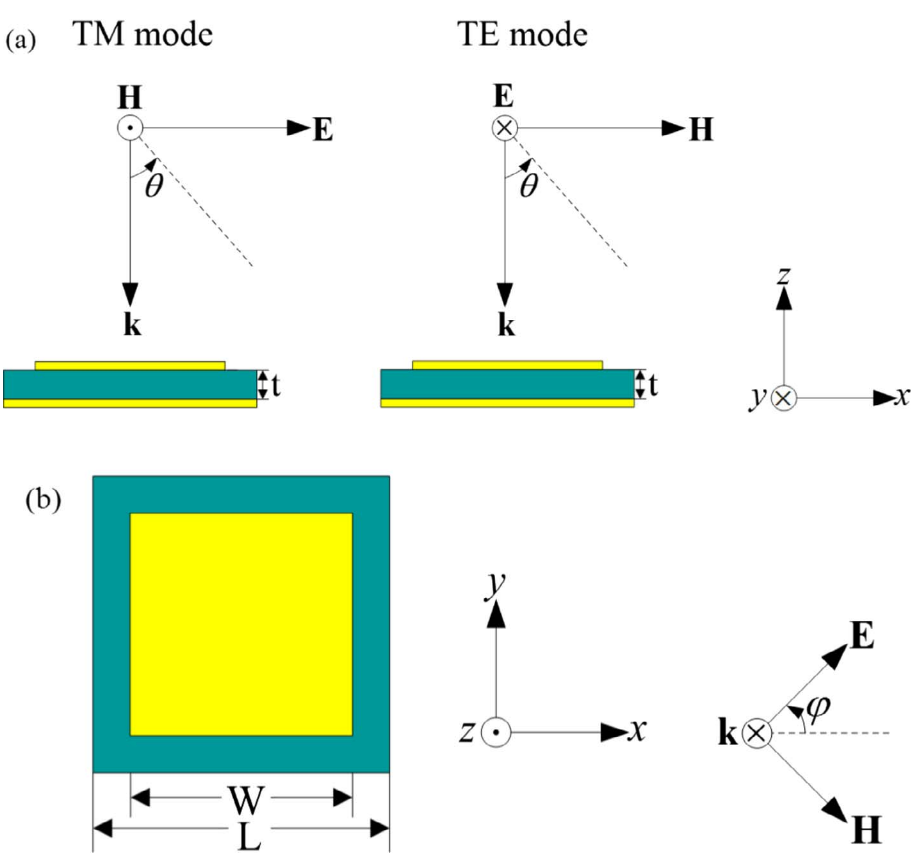

Fig. 2. Illustration of the coordinates and the incident electromagnetic wave: (a) side view, (b) front view.