Design of a type of a multilayer metamaterial absorber for microwave broadband

Zelun Li [1, a], Mengtao Yang [1, b], Xianling Deng [1, c], Jianhui Li [1, d], Zhicheng Huang [2, e]

[1]College of Mechanical and Power Engineering, Chongqing University of Science and Technology, Chongqing 401331, China;

[2] School of Mechanical and Electronic Engineering, Jingdezhen Ceramic Institute, Jingdezhen 333403, China.

[a]instru@163.com, [b]309228973 @qq.com, [c]dengxianling2013@126.com, [d]ljh_hit@126.com, [e]huangwu555@sina.com

Abstract

At present, absorber is one of the most important applications of metamaterials, which is a kind of functional structure or device that can absorb the energy of electromagnetic wave incident on its surface with good effect. In the field of absorber research, researchers have found many deficiencies of the absorber materials that are used currently, such as narrow frequency band, low absorption efficiency, large geometric size, etc., which limit its application scope. Therefore, finding compatible absorbing materials is one of the directions for research and development in this field. A multilayer metamaterial absorbing structure suitable for microwave broadband is put forward in this paper, and absorbing mechanism and band widening technology of multilayer metamaterial absorber are further studied.

Keywords

Multilayer metamaterial, absorber, microwave broadband.

1. Introduction

As a basis on which human society relies for existing and developing, the discovery and application of materials are changing people's lives. In recent years, electromagnetic metamaterials, as a emerging subject, have attracted wide attention of many scientific research institutions at home and abroad. Since ″Metamaterials″ is the English name of electromagnetic metamaterials, and the word ″Meta″ itself also expresses the meaning of ″alternative″ and ″supernormal″, so they are called metamaterials. Generally speaking, metamaterials refer to a kind of artificial-prepared sub-wavelength periodic structure, which have supernormal physical properties that natural materials do not have, such as negative magnetic conductivity, magnetic conductivity, double negative dielectric constant, negative refraction, sub-wavelength super-transmission, etc[1]. Since Landy and other researchers first designed a resonant absorber based on electromagnetic metamaterials in 2008 that can absorb electromagnetic waves at specific wavelengths ″perfectly″[2], metamaterial absorber has begun to enter people's mind and developed rapidly.

At present, the design and development of absorber based on metamaterials in the fields of electromagnetic stealth, bolometer and thermal emission is developing vigorously[3-4], especially in aviation, the surface of aircraft can be coated with metamaterial absorbers to reduce their scattering cross sections, thus avoiding tracking and detection. Moreover, metamaterial absorber can reduce sidelobe radiation of antenna, enhance directional radiation and improve performance of antenna. In addition, metamaterial absorber can also reduce the electromagnetic leakage of various electronic devices and reduce the impact of electromagnetic waves on human body and environment. Thus, metamaterial absorber has a wide range of practical applications and good application prospects[5-8].

Compared with traditional absorbing materials, metamaterial absorbing structure has obvious advantages in the following aspects: first of all, the thickness of many traditional electromagnetic metamaterials is required to be $\lambda_0/4$ (λ_0 is central frequency of incident wave), but the appearance of metamaterials has greatly reduced this thickness. According to the recent report, the thickness of absorber made of metamaterial is $\lambda_0/75$, which is much thinner than that of traditional absorbers. Secondly, the absorption frequency of a metamaterial absorber can be easily adjusted by changing the structure and size of the resonant element or the substrate material. The absorption frequency of traditional absorbing materials is very difficult to change. Recently, as more and more electronic equipment choose metamaterials to achieve their high-performance electromagnetic stealth, we have reason to believe that the electromagnetic absorber based on metamaterials is a kind of high-performance electromagnetic stealth materials with good development prospects[9-11].

In this paper, a multilayer metamaterial absorbing structure suitable for microwave broadband is put forward, and absorbing mechanism and band widening technology of multilayer metamaterial absorber are further studied, including the following two aspects of specific research contents.

2. Design of multilayer metamaterial absorbing structure

For multilayer metamaterials absorbing structure, according to the propagation principle of electromagnetic wave in the medium and the corresponding boundary conditions, the total reflection coefficient of electromagnetic wave can be described as:

$$\begin{aligned} r = & \frac{e^{j2k_z d_0}}{r_{01}} + \frac{[1-(1/r_{01}^2)]e^{j2(k_{1z}+k_{0z})d_0}}{(1/r_{01})e^{j2k_{1z}d_0}} + \frac{e^{j2k_{1z}d_1}}{r_{12}} + \\ & \frac{[1-(1/r_{12}^2)]e^{j2(k_{2z}+k_{1z})d_1}}{(1/r_{12})e^{j2k_{2z}d_1}} + \dots + \frac{e^{j2k_{(n-1)z}d_{n-1}}}{r_{(n-1)n}} + \\ & \frac{[1-(1/r_{(n-1)n}^2)]e^{j2(k_{nz}+k_{(n-1)z})d_{(n-1)}}}{(1/r_{(n-1)n})e^{j2k_{nz}d_{(n-1)}}} - 1 \end{aligned} \tag{1}$$

Among them, $r_{01}, r_{02}, \dots r_n$ are the reflection coefficient from the first to the nth interface respectively, $d_1, d_2, \dots, d_n$ are the thickness of the dielectric layer from the first to the nth interface respectively.

The electromagnetic absorbility of absorbing materials can be expressed as:

$$A = 1 - r^2 \tag{2}$$

The absorbing characteristics of multilayer metamaterial absorbing structure can be obtained from the above.

It can be seen from the formula (1) that the absorbing properties of the multilayer metamaterial absorbing structure are directly related to the resonant element structure, the thickness of the dielectric layer and the dielectric constant, so it is difficult to solve the formula (1) directly. Therefore, the project team intends to establish a simplified equivalent model by introducing resonant elements and equivalent factors of dielectric property on this basis, thereby studying the geometric parameters of the structure and the influence of the dielectric material on the absorption performance and providing optimization measures of absorbing structure performance.

3. Planarization of multilayer metamaterial absorber

The absorbing principle of multilayer metamaterial absorbing structure is the reflection cancellation of electromagnetic wave propagation in dielectric layers, so the key to reduce the thickness of multilayer metamaterial absorbing structure is to ensure that the phase difference between the reflected wave and the incident wave is $(2n+1)\pi$ under the circumstance that all dielectric layers are as thin as possible. In consideration of the limitation of dielectric material selection, the project team will focus on the effect of the resonant element topological structure on the interface reflection, and further analyze the correlation between the size parameters of the resonant structure and the reflection coefficient. Based on the topological structure of resonant elements with four-directional symmetry or rotational symmetry, absorption band widening technology focuses on the influence of topological structure unit on absorption peak bandwidth and the arrangement of resonant elements in different layers so as to meet the requirements of broadband absorption of multilayer metamaterial absorbing structure. Since resonant element itself will produce absorption peak with fixed frequency through electromagnetic resonance, the project team intends to further increase the absorption bandwidth by optimizing the size of resonant structure, so that the resonant absorption frequency is close to the absorption band obtained by the principle of reflection cancellation.

The planarization technique of multilayer metamaterial absorbing structure and the technology of absorption band widening can be further analyzed by means of electromagnetic simulation software (CST MWS, HFSS, etc.). By studying the internal electric field, surface current and loss distribution of multilayer metamaterial absorbing structure at the corresponding absorption frequency, the resonant mode distribution and optimization scheme of electromagnetic wave absorbility can be obtained, which lays a foundation for the performance optimization of multilayer metamaterial absorbing structure.

4. Conclusion

On the basis of the theoretical study of multilayer metamaterial absorber, the multilayer metamaterial absorbing structure for Ka band is designed and the multilayer metamaterial absorbing structure with absorbility greater than 90%, total thickness less than 5mm and absorption bandwidth larger than 5GHz is obtained.

Acknowledgements

This research is funded by Chongqing Research Program of Basic Research and Frontier Technology (No. cstc2018jcyjAX0291).

References

[1] S. Clemens, M. Iskander. Hybrid Genetic Programming for the Development of Metamaterials Designs With Improved Characteristics. IEEE Antennas and Wireless Propagation Letters. 2018, 17(3): 513–516.

[2] N. Landy, S. Sajuyigbe, J. Mock, et al. Perfect Metamaterial Absorber[J]. Physical Review Letters. 2008, 100 (20): 207402.

[3] M. D. Banadaki. A. A. Heidari, M. Nakhkash. A Metamaterial Absorber With a New Compact Unit Cell. IEEE Antennas and Wireless Propagation Letters, 2018, 17(2): 205–208.

[4]P. Rufangura, C. Sabah. Polarisation insensitive tunable metamaterial perfect absorber for solar cells applications. IET Optoelectronics, 2016, 10(6): 211–216.

[5] B. Wang, X. Zhai, G. Wang, et al. Design of a Four-Band and Polarization-Insensitive Terahertz Metamaterial Absorber. IEEE Photonics Journal. 2015, 7 (1): 4600108.

[6] B. Zhu, Z. B. Wang, Z. Z. Yu, et al. Planar Metamaterial Microwave Absorber for All Wave Polarizations. Chinese Physics Letters. 2009, 26(11): 114102.

[7] M. Soheilifar, Design, Fabrication, and Characterization of Scaled and Stacked Layers Metamaterial Absorber in Microwave Region. Microwave and Optical Technology Letters. 2016, 58(5):1187-1193 .

[8] H. Tao, C. Bingham, D. Pilon, et al. A Dual Band Terahertz Metamaterial Absorber[J]. Journal of Physics D: Applied Physics. 2010, 43 (22): 225102.

[9] Y. Zhi Cheng, Y. Wang, Y. Nie, et al. Design, Fabrication and Measurement of a Broadband Polarization-Insensitive Metamaterial Absorber Based on Lumped Elements[J]. Journal of applied physics. 2012, 111 (4): 044902.

[10] F. Ding, Y. Cui, X. Ge, et al. Ultra-Broadband Microwave Metamaterial Absorber[J]. Applied Physics Letters. 2012, 100 (10): 103506.

[11] J. Sun, L. Liu, G. Dong, et al. An Extremely Broad Band Metamaterial Absorber Based on Destructive Interference. Optics Express. 2011, 19 (22): 21155-21162.