IOP Conf. Series: Materials Science and Engineering **322** (2018) 022029 doi:10.1088/1757-899X/322/2/022029

A Wide Band Absorbing Material Design Using Band-Pass Frequency Selective Surface

Yonggang Xu[1,*], Qiang Xu[1], Ting Liu[2], Dianliang Zheng[2], Li Zhou[2]

[1] Shanghai Radio Equipment Research Institute, Shanghai, China
[2] College of Aeronautical Engineering, Jilin Institute of Chemical Technology, Jilin, China

*Corresponding author e-mail: xuyonggang221@221.com

Abstract. Based on the high frequency advantage characteristics of the Fe based absorbing coating, a method for designing the structure of broadband absorbing structure by using frequency selective surface (FSS) is proposed. According to the transmission and reflection characteristic of the different size FSS structure, the frequency variation characteristic was simulated. Secondly, the genetic algorithm was used to optimize the high frequency broadband absorbing materials, including the single and double magnetic layer material. Finally, the absorbing characteristics in iron layer were analyzed as the band pass FSS structure was embedded, the results showed that the band-pass FSS had the influence on widening the absorbing frequency. As the FSS was set as the bottom layer, it was effective to achieve the good absorbing property in low frequency and the high frequency absorbing performance was not weakened, because the band-pass FSS led the low frequency absorption and the high frequency shielding effect. The results of this paper are of guiding significance for designing and manufacturing the broadband absorbing materials.

1. Introduction

The microwave absorbing material has a good effect to avoid the harm of electromagnetic radiation and electromagnetic interference of electronic equipment. The absorbing materials include Fe based absorbing materials, conducting polymers, chiral absorbing materials, FSS and so on, all of them have been extensively studied [1-3]. However, it is difficult to satisfy the four properties of "thin", "light", "wide" and "strong" for the above absorbers. For example, the iron based microwave absorbing material can achieve the higher absorption in thinner thickness, but it is difficult to realize the broadband absorption because of its large density. While the frequency selective surface can achieve the lower density at a certain thickness, and can overcome the deficiency of the former two type absorbers, but the bandwidth is narrow. Therefore, how to develop absorbing materials with the good characteristics has still been a problem that researchers need to solve.

According to the characteristics of Fe based absorbing materials, they have higher Snoek limit and saturation magnetization at GHz, the microwave absorbing material based on it can reduce the microwave absorption bandwidth and make it easier to achieve the characteristics of thin thickness. Carbonyl iron absorbing material can achieve better absorbing performance in the frequency range of 8-18GHz. For example, when the spherical carbonyl iron material filling ratio reached 60%, the thickness of 1mm, the reflectivity can reach -12.2dB [4], when the weight addition ratio is 55%, the reflectivity at 10.6GHz can reach -42.5dB [5]. FSS has the characteristics of the band pass or the band

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

stop, and it can achieve better absorption effect in the resonant frequency band. Peng Han constructed the tunable band pass FSS using dielectric ceramics and ferrites, in waveguide mode for C-band, the two structures were coupled at the same frequency point by electromagnetic resonance, the transmission effect of "double negative" pass band could be brought about [6]. In addition, BaSrTiO3 ceramics including band-pass FSS was studied using the traditional solid-phase sintering method [7], which was based on the theory of equivalent medium under quasi-static condition and the theory of dielectric resonance. The extraction results of equivalent parameters are numerically analyzed, it is determined that electromagnetic resonance is the main cause of pass band, and the formation mechanism of resonant modes and through resistance characteristics is further determined. Therefore, a new approach might be effective for the preparation of broadband absorbing materials combining Fe based absorbing materials with FSS and taking advantage of these two advantages.

In this paper, we proposed the carbonyl iron absorbing material and the band pass FSS as the research object, and the band pass type FSS was used to regulate the absorbing properties of magnetic absorbing materials. Firstly, the absorption characteristics of band pass type FSS and the influence of structure size on its absorbing properties were analyzed. Secondly, the broadband design was carried out using the genetic algorithm for the high frequency absorbing materials. Finally, based on the design of high frequency absorbing materials, the influence of band pass type FSS on its bandwidth was analyzed.

2. Material and methods

2.1. Materials preparation

The carbonyl iron absorbing powder was prepared with the flake structure by the ball milling process. Then the different components of the carbonyl iron absorbing material were prepared as a magnetic absorbing material. The morphology of the carbonyl iron particle was obtained by the scanning electron microscopy (SEM CamScan CS3400). The average diameter of flaky carbonyl iron particles was about 5μm, and the thickness was about 0.5μm. The electromagnetic parameter measurement was accomplished by a vector network analyzer that connected the transmission line. The sample was the coaxial specimen, the thickness of the sample was 2 mm, the outer diameter was 7 mm, and the inner diameter is 3 mm. S_{11} and S_{21} were measured, then according to the Nicolson-Ross-Weir algorithm, the electromagnetic parameters of the material could be calculated.

2.2. Design of band pass type FSS structure

According to the absorption characteristics of FSS, the design of the whole absorbing structure which mainly was consisted of two layers based on the band pass type FSS. As shown in Fig.1, the first layer is a metal square ring, and the second layer is a dielectric plate. When the electromagnetic microwave is incident, the internal bending structure increases the equivalent inductance of the element. The compact cell spacing increases the coupling capacitance, which can greatly reduce the resonant frequency of the cell and make the unit smaller, and the induced current will be dissipated in the metal film due to excitation on the loop. In order to design the microwave absorbing effect of the band pass FSS, the CST software was used to simulate the metamaterial absorber based on the finite integral method. The designed parts include: the impedance surface which uses PF4 plastic film as the support medium and the copper foil which is used for metal square ring. The dielectric constant of PF4 plastic film is 4.4-*j*0.03, and the thickness is 2mm~6mm. The thickness of copper foil is 0.018mm, and the conductivity is 5.8×10^7 S/m.

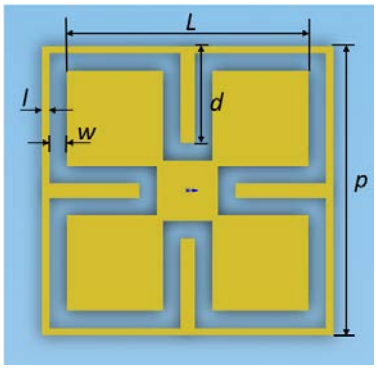

Fig.1 FSS unit structure

2.3. Structure design of band pass FSS embedded iron based absorbing material

Based on the transmission/reflection characteristics of band pass FSS, frequency superposition method is adopted for broadband design of the absorbing material. The full band 1~18 GHz is divided into two parts: 1~8 GHz and 8~18 GHz. Composites of these two absorbing structures are selected according to two frequency ranges.

The transmission and reflection characteristics of two-layer absorbing structures are shown in Fig.2. It could be seen that when the low frequency 1~8 GHz electromagnetic microwave was incident on the surface microwave absorbing material most of them passed through, which was incident to the band pass FSS absorbing structure. Then, one part of the electromagnetic microwave was lost, and another part was reflected back to the magnetic absorbing materials and most of them transmitted the magnetic absorbing layer. The band-pass type FSS could be regarded as the shielding layer when the electromagnetic microwave of high frequency 8~18 GHz was directly incident to the surface magnetic layer. High frequency electromagnetic microwave could be directly lost in the surface magnetic layer and finally was attenuated broadband.

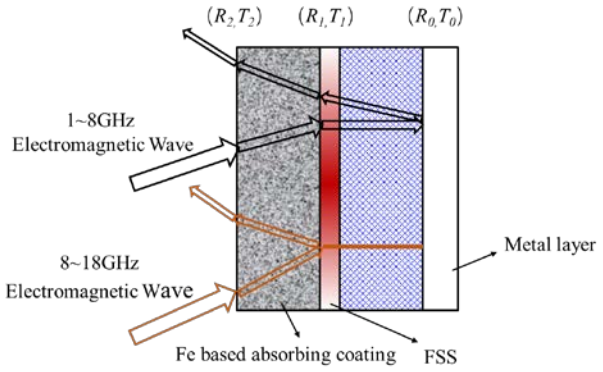

Fig.2 The structure model diagram of the designed magnetic absorbing materials using FSS

3. Results and discussion

3.1. Influence of medium with different thickness to transmission/reflection characteristics

For band pass type FSS, the selected length was as follows, p=10mm, l=0.2mm, w=0.6mm, d=4.2mm, and the thickness of the PF4 plastic dielectric plate is 2mm~6mm, then the influence of dielectric plate with different thickness on its electromagnetic properties is analyzed. The transmission/reflection characteristic curve is shown in Fig.3. As can be seen from the diagram, the band-pass frequency moves as the thickness of the dielectric plate increases. The reflection coefficient amplitude is close to 0.1 at near 3.4GHz, and the transmission coefficient amplitude is close to 0.95. At this frequency point, the electromagnetic microwave is in full transmission state. In the range of frequency 10~12GHz, the second resonance peak appears, and the different thickness has a greater influence on the peak frequency. When the frequency is above 14GHz, as the frequency increases it

can be seen that the reflection coefficient has the third and the fourth peaks, but the peak frequency is not monotonic with the increase of substrate thickness. Meanwhile, the transmission coefficient peaks at the corresponding frequency points also exist and shows good transmission performance.

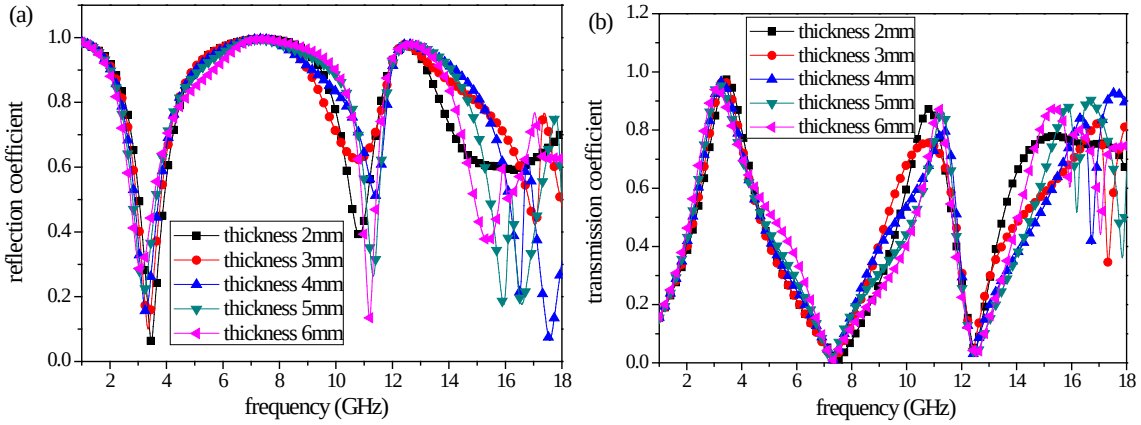

Fig.3 FSS characteristics with different thickness, (a) reflection coefficient, (b) transmission coefficient

3.2. Broadband design of multilayer magnetic microwave absorbing materials inserted FSS

The multilayer absorbing material was designed, and the main parameters included the material composition, thickness, dielectric constant and permeability of each layer. Based on the previous research and analysis on the various carbonyl iron absorber, whose absorbing performance at the high frequency could be optimized by using the genetic algorithm, and the optimization variables are the ratio and thickness of each layer of the material [8, 9]. In this paper, the optimized frequency band is 8~18GHz, the optimized objective function is reflectivity, and the reflectivity requirement is less than -10dB. After the optimizing process, a high-frequency absorbing materials could meet the requirements with RL less than -10 dB. It included two layers, the first layer was the 10% carbonyl iron composite with thickness 1.21mm, the second layer was 40% carbonyl iron composite with thickness 0.54mm. The RL curve as a function of frequency is shown in Fig.4. The absorbing properties of materials are linearly decreased in the low frequency range, which is only about -0.5dB at 1GHz and indicates that the absorption effect of the carbonyl iron material is better in the high frequency, while the low frequency performance is insufficient under the condition of limited thickness.

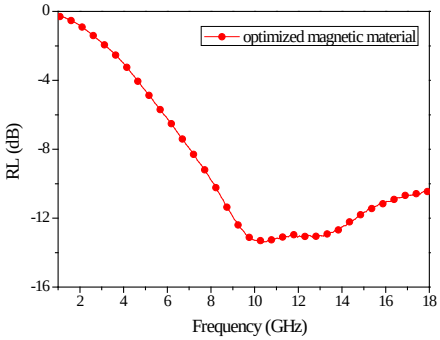

Fig.4 RL curve of the optimized single or double layer absorbing materials

The reflection loss simulation was calculated in the CST software. The results of reflectivity calculation are shown in Fig.5. It could be obtained that by increasing the thickness of the band pass type FSS, the RL in low frequency band was effectively decreased, while the better broadband microwave absorption characteristics was achieved in the high frequency. Narrow microwave absorption occurs near 2GHz, and broadband microwave absorbing properties are better in range of 5~8GHz. Meanwhile, the reflectivity of implanted the normal FSS is lower than -20dB. With the increase of the thickness of the band-pass type FSS, the peak frequency of the reflectivity shifts to the low frequency, which is consistent with the previous simulation results. After the implantation of FSS,

with the change of the thickness of band pass type FSS, the reflectivity remains at -8.8dB in the range of 8~18GHz, indicating that the high frequency absorption performance can be guaranteed on the basis of widening the low frequency wave absorbing performance, which is consistent with the previous design idea.

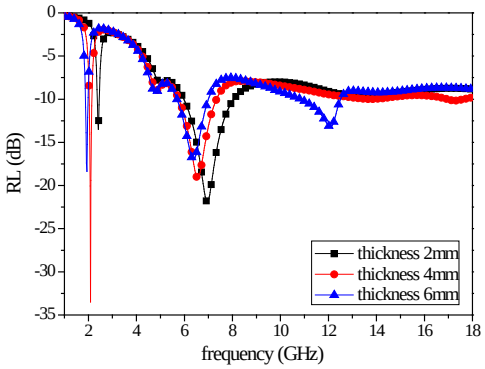

Fig.5 RL of the designed absorbing materials inserted FSS

3.3. Enhancement mechanism of band-pass FSS on the absorption of multi-layer absorbers

In order to demonstrate the enhancement effect of the FSS type absorber on the electromagnetic microwave, the reflection/transmission coefficient of the three-layer absorber containing the two type FSS absorber was analyzed. The reflection coefficient (R_c) and transmission rate (T_r) of the multilayer absorber was simulated as shown in Fig.6. It could be obtained the multilayer absorber without the metal plate had a close R_c compared with the RL. However, the absorbing property was different from the absorber backed by the metal at 1-4 GHz, and the minimum R_c was close to -14.5 dB, and T_r was close to 0 in 8-18 GHz which meant that the absorbing property at the frequency band was very weak. While the CIPs layer had the small S_{11} and large S_{12} in 1-4 GHz, S_{11} increased and S_{12} decreased as the frequency increased to 18 GHz, which meant that the absorbing property increased. Compared with the two layer absorber with the single FeSi layer, it could be found that S_{11} and S_{12} was very close, and as the metal plate was backed to the two layer absorber, the S_{11} value decreased in the low frequency, as well as the high frequency range. It could be considered that the absorbing in the low frequency range could be kept partly, while the absorbing property in the high frequency could be weak because the S_{11} value was smaller than that of the single CIPs layer absorber.

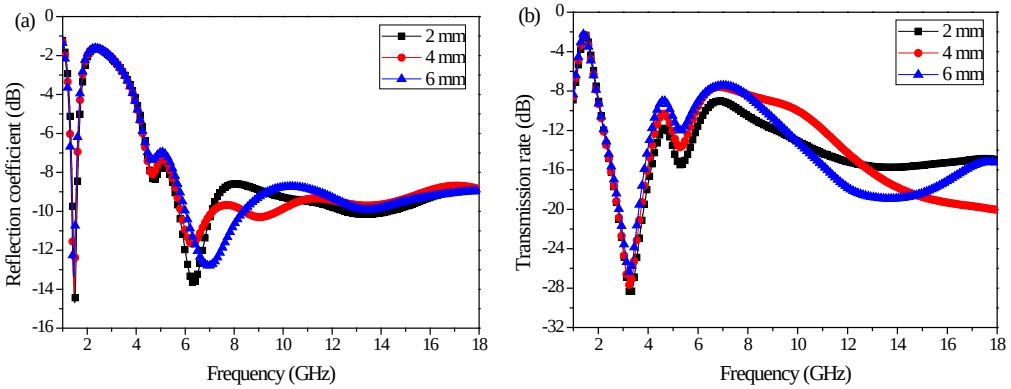

Fig.6 Reflection and transmission property of the multilayer materials, (a) Rc, (b) Tr

The analysis shows that band pass type FSS can transmit and loss low frequency electromagnetic wave, and can shield high frequency electromagnetic wave. High frequency electromagnetic wave can be effectively lost when incident into the surface of iron based absorbing material. When the microwave reaches the FSS surface, it can be reflected directly and achieve the second or more losses, as a result, the electromagnetic wave of high frequency will be lost in the iron based absorbing material.

4. Conclusion

For different sizes of FSS, the variation of frequency band is analyzed, broadband microwave absorbing structures are constructed by using band pass type FSS. The results show that band pass type FSS has better effect in expanding frequency band, especially for the optimized two-layer carbonyl iron absorbing materials, whose reflectivity can be remained about -10 dB at high frequencies. The results of this research have some guiding significance for the design and manufacture of broadband microwave absorbing materials.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (Grant No. 61601299, 61701308, 11404213), the National Natural Science Foundation of Shanghai (Grant No. 16ZR1445700) and the Science Foundation of Jilin Institute of Chemical Technology (Grant No 2014068).

References

[1] Micheli, D., Apollo, C., Pastore, R., & Marchetti, M., X-band microwave characterization of carbon-based nanocomposite material, absorption capability comparison and RAS design simulation. Composites Science & Technology, 70 (2010), 400-409.
[2] LEE SANG-EUI, CHOI OYOUNG, H.Thomas, et al. Micromicrowave properties of graphite nanoplatelet/epoxy composites[J]. Journal of Applied Physics,2008,104(3):033705-033705-7.
[3] Itoh, M., Liu, J. R., Horikawa, T., & Machida, K. I., Electromagnetic wave absorption properties of nanocomposite powders derived from intermetallic compounds and amorphous carbon. Journal of Alloys & Compounds, 408–412 (2006), 1400-1403.
[4] Lebourgeois, R., Fur, C. L., Labeyrie, M., Paté, M., & Ganne, J. P. (1996). Permeability mechanisms in high frequency polycrystalline ferrites. Journal of Magnetism & Magnetic Materials, 160(96), 329-332.
[5] Zhang, B., Feng, Y., Xiong, J., Yang, Y., & Lu, H. (2006). Microwave-absorbing properties of de-aggregated flake-shaped carbonyl-iron particle composites at 2-18 ghz. IEEE Transactions on Magnetics, 42(7), 1778-1781.
[6] Peng, H., Jun, W., Jia-Fu, W., Hua, M., Teng-Qiang, S., et al, Design and research of magnetic tunable frequency selective surface based on dielectric and ferrite. Acta Mathematica Scientia, 65 (2016): 250-259.
[7] Han P, Yu F, Zhang J Q, et al, Microwave characteristics and design of frequency selective properties based on Barium Strontium Titanate. China Science Bulletin, 61(2016) 3278-3287.
[8] Yuan J, Xiao G,Cao MS. A novel method of computation and optimization for multi-layered radar absorbing coatings using open source software. Materials and Design, 27 (2006) 45-52.
[9] Goudos S.K. A versatile software tool for microwave planar radar absorbing materials design using global optimization algorithms. Materials and Design, 28(2007) 2585-2595.