Advanced Materials Research *Online: 2014-02-06*
ISSN: 1662-8985, Vols. 887-888, pp 432-436
doi:10.4028/www.scientific.net/AMR.887-888.432

Analysis and Design of Transparent Microwave Absorbing Materials Based on the Destructive Interference at the Microwave Range

Yi Ye[1,2,a], Lixin Song[1], Xianglian Song[1,2] and Tao Zhang[1,b]

[1]The key Laboratory of Inorganic Coating materials, Shanghai Institute of Ceramics, Chinese Academy of Sciences, 1295 Dingxi Road, Shanghai, 200050, P. R. China

[2]University of Chinese Academy of Sciences, 19 Yuquan Road, Beijing, 100049, P. R. China

[a]yeyi@student.sic.ac.cn, [b]tzhang@mail.sic.ac.cn(corresponding author)

Key words: microwave absorbing material; destructive interference; reflection intensity

Abstract. An optically transparent microwave absorbing material based on the destructive interference theory was studied in this paper. The destructive interference phenomenon has been discussed and verified in the transparent microwave absorbing material. According to the destructive interference theory, we designed a type of three-layer microwave absorbing structure to enlarge the absorbing bandwidth. And its reflection coefficient curve stays below -10dB in the range of 7.5GHZ to 17.0GHz.

Introduction

Microwave absorbing material can absorb the incident microwave effectively and thus reduce the microwave reflectivity, to protect the target under irradiation. After the Second World War, many types of microwave absorbing material have been studied, such as carbon black [1, 2], iron oxide [3], carbon nanotube [4], carbonyl iron [5] and so on. However, these materials are not suitable for transparent devices because of their low transmittance at visible wavelengths. Transparent stealth devices require not only visible transparence but also microwave absorbing [6]. Therefore, another type of microwave absorbing material has been studied to solve the problem. By using suitable materials, specific structure can absorb the incident microwave gradually [7].

The first type of structure microwave absorbing material was called Salisbury screen [7], consisting of a resistive sheet, a high reflective ground and a quart-wavelength dielectric layer, and was the primary type. And later, by using more dielectric layers and resistive sheets, it increased absorbing bandwidth, which was called Jaumann absorber [8]. Another improvement was obtained by replacing the resistive sheets in Salisbury or Jaumann absorber with period pattern resistive sheets, which was named circuit analog absorbers. Absorbing bandwidth, reflection intensity and material thickness are the major elements for such absorbers. However, most microwave absorbing materials have inherently small relative bandwidth [9].

For getting a transparent microwave absorbing material, we build a structure consisting of transparent resistive sheets and transparent dielectric layers. A wide set of materials such as transparent conductive oxide films and commercial carbon-based resistive inks can be used as the transparent resistive sheets [10]. By adjusting the process parameters, the square resistance of the resistive sheets can be controlled to meet the design requirements. And the dielectric layers will choose from transparent materials such as glass, quartz-glass, sapphire, PET and so on, according to their permittivity. In this paper, we aimed to design a transparent microwave absorbing material having a large relative bandwidth and analyze the efficiency of the design through the interference of microwave.

Destructive interference theory of the microwave absorbing materials

For a simple design, it is constructed by a dielectric layer with a resistive sheet on the top surface and a high reflective ground under the bottom surface. When the microwave incident on the screen vertically, the reflections will occur at the resistive sheet and the high reflective ground respectively. These two microwaves reflected have the same frequency and vibrating direction and the phase difference between them is constant, meanwhile the wave path difference between them is the twice of the thickness(d) of the dielectric layer. If the product of dielectric layer thickness and refractive index(n) equals to a quarter reference wavelength(λ), the optical path difference of these two microwaves reflected exactly half a reference wavelength, which will occur the destructive interference. This reference wavelength(λ) can be calculated by Eq.1:

$$nd\cos\theta = m\frac{\lambda}{4} \tag{1}$$

θ is the incident angle and m = 1, 3, 5, 7……. The refractive index of the dielectric layer on the microwave spectrum cannot be obtained directly, but can be calculated through the value of permittivity(ε_r):

$$n = \sqrt{\varepsilon_r} \tag{2}$$

When the thickness and permittivity of the dielectric layer and the reference frequency(υ) conform to the formula, the intensity of the reflected microwave on the reference frequency will be reduced, due to the destructive interference.

$$\nu = m\frac{c}{4d\cos\theta\sqrt{\varepsilon_r}} \tag{3}$$

Results and discussions

The primary microwave absorbing material is one layer design, the structure showed in Fig. 1. It consists of a transparent resistive sheet, a high reflective ground and a transparent dielectric layer. According to the destructive interference theory, we can get the reflection characteristics. When the thickness and permittivity of the dielectric layer are decided, there should be several corresponding absorption peaks on the operating frequency range. The frequency of these absorption peaks can be calculated by Eq.3, through the parameters of the dielectric layer.

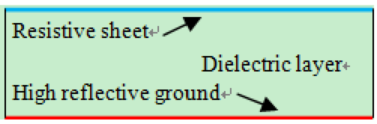

Fig.1 One layer transparent microwave absorbing material

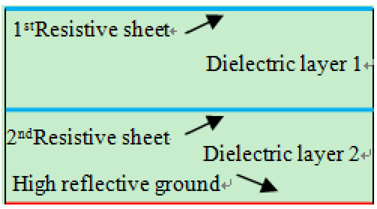

Fig.4 Two layers transparent microwave absorbing material

Fig. 2 shows the reflection results of the one layer design. We found that several narrow absorption peaks appear regularly on the operating frequency range. This situation consists with the prediction of destructive interference theory. In order to verify the matching of results and formula, we chose the first absorption peak of every curve, when the value of parameter m is one, and then calculated their theoretical value by the parameters of the dielectric layer. From the comparison in table 1, we can see that the values of results and calculated results are approximatively the same. As a result, the frequency of the absorption peak can be selected by adjusting the thickness and permittivity of the transparent dielectric layer.

Table 1: Comparison of the results and calculated results

thickness(mm)	permittivity	absorption peak (result/GHz)	Absorption peak (calculated/GHz)
8	4	4.6	4.688
8	5.5	4.0	3.997
8	7	3.6	3.543
6	5.5	5.4	5.330
5	5.5	6.4	6.396

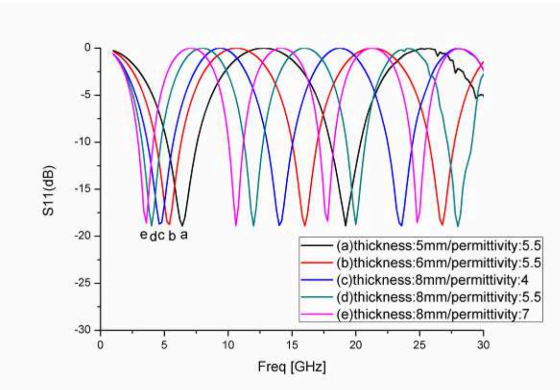

Fig.2 The reflection results of the one layer design with different thickness and permittivity of the dielectric layer

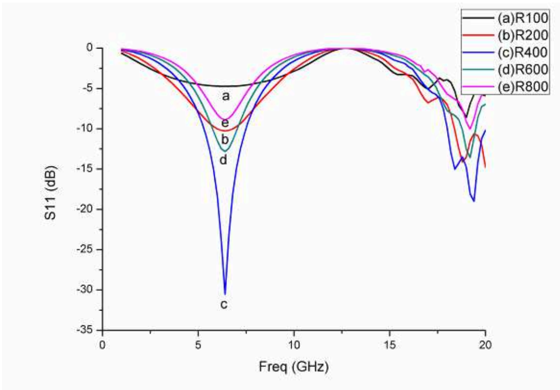

Fig.3 The reflection results with the same dielectric layer and different resistive sheets

Comparing the reflection results with different thickness and permittivity of dielectric layer, the intensities of different absorption peaks are almost equal. This situation shows that, for transparent dielectric materials such as glass and quartz, the electric dissipation occurring within the materials is too small so we can ignore it in the destructive interference theory.

Fig. 3 shows the reflection results with the same dielectric layer and different resistive sheets. The frequency of absorption peaks is invariable, but the intensity of absorption peaks increases as the square resistance of resistive sheets increases from 100Ω/□ to 400Ω/□ and then decreases as the square resistance increases from 400Ω/□ to 800Ω/□. According to the destructive interference theory, the intensity of the absorption peak depends on the difference value between the intensities of two microwave reflected at the resistive sheet and the high reflective ground. In theory, the microwave reflection at the high reflective ground is complete. Therefore, when the energy of the microwave reflected at the resistive sheet is 50% of the incident microwave, the energy of the microwave reflected at the high reflective ground is also 50% and these two microwaves with the same wave amplitude will cancel each other out and the intensity of the absorption peak achieves to the extreme value. As the reflectivity at the resistive sheet increases or decrease from 50%, the intensity of the absorption peak will decrease obviously. The reflectivity of the microwave reflected at the resistive sheet depends on the square resistance of the resistive sheet and it will decrease as the square resistance increasing. So we can control the intensity of the absorption peak by adjusting the square resistance of the resistive sheet.

It is difficult to get a wider bandwidth of transparent microwave absorbing materials by using only one layer absorber. So we designed a structure of two layers microwave absorbing materials, just as shown in Fig. 4. It consists of two transparent resistive sheets, two transparent dielectric layers and a high reflective ground. According to the description above, destructive interference will occur twice, once between the first resistive sheet and the high reflective ground and the other between the first resistive sheets and the second resistive sheet. By adjusting the thickness and permittivity of the dielectric layers, we tried to distribute the absorption peaks caused by twice of destructive interferences uniformly on the operating frequency range.

Fig. 5 shows the reflection results of the two layers designs. The first sheet is important to ensure that there is enough incident microwave entering into the structure, so the square resistance was fixed to 400Ω/□. The square resistance of the second sheet was increased from 50Ω/□ to 400Ω/□. When the value is too large to reflect enough incident microwave at the second resistive sheet, the reflection curve is similar to the one layer structure having the sum of thickness. On the other hand, when the value is decreased to a certain extent, the microwave is hard to transmit to the high reflective ground, for which the reflection curve is similar to the one layer structure having the thickness of the first dielectric layer. It is significant to control the square resistance of the interlayer resistive sheet at a suitable value so that the two reflection curves combine together appropriately.

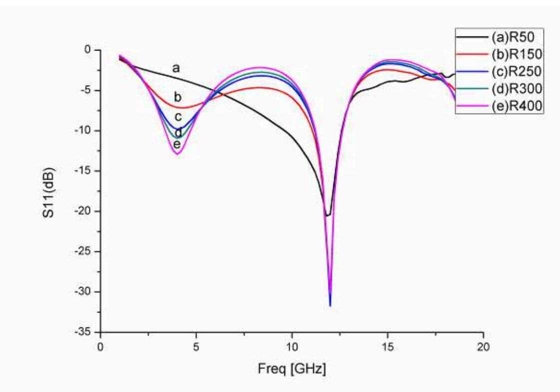

Fig.5 The reflection results of the two layers designs (the square resistance of 2nd sheet from 50Ω/□ to 400Ω/□)

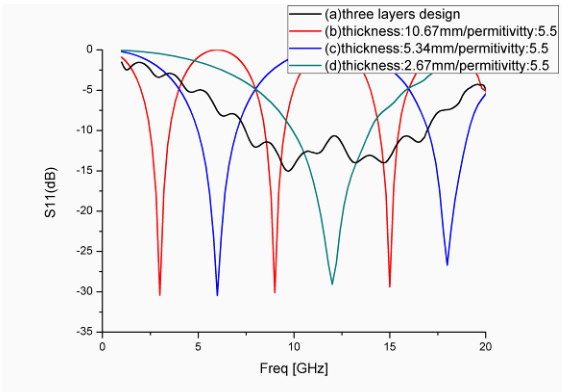

Fig.6 The reflection results of the three layers designs (the square resistance of 2nd sheet from 50Ω/□ to 400Ω/□)

According to the conclusion above, the more layers the microwave absorbing materials have, the better bandwidth of the materials we can get. A three layers microwave absorbing material was designed using destructive interference theory. Here, the value of square resistance we can get from designing and optimizing is R1 = 2000Ω/□, R2 = 110Ω/□, R3 = 40Ω/□. From Fig. 6, we can see that the absorption peaks caused by three groups of destructive interferences are distributed uniformly on the operating frequency range. And we can learn that the reflection curve of the three layers microwave absorbing material has a good bandwidth, its reflection coefficient curve stay below -10dB in the range of 7.5GHZ to 17.0GHz.

Conclusions

In this paper, destructive interference theory is used to analyzing the multilayer microwave absorbing materials. When we design the multilayer microwave absorbing materials, we can control the absorption range through adjusting the thickness and permittivity of the dielectric layers, and then optimize the square resistance of the resistive sheets to get a structure having the good bandwidth and absorbing intensity. These conclusions can give crucial clues in designing a transparent microwave absorbing material.

References

[1] J.H. Oh, K.S. Oh, C.G. Kim, C.S. Hong, Design of radar absorbing structures using glass/epoxy composite containing carbon black in X-band frequency ranges, Composites Part B. 35 (2004) 49-56.

[2] J.B. Kim, J.H. Byun, Salisbury screen absorbers of dielectric lossy sheets of carbon nanocomposite laminates, IEEE Trans. Electromagn. Compat. 54 (2012) 37-42.

[3] H.K. He, C. Gao, Supraparamagnetic, conductive and processable multifunctional grapheme nanosheets coated with high-density Fe3O4 nanoparticles, ACS Appl. Mater. Interfaces. 2 (2010) 3201-3210.

[4] K.Y. Park, S.E. Lee, C.G. Kim, J.H. Han, Fabrication and electromagnetic characteristics of electromagnetic wave absorbing sandwich structures, Compos. Sci. Technol. 66 (2006) 576-584.

[5] Q.W. Ding, M.G. Zhang, C.R. Zhang, T.W. Qian, Synthesis and absorbing mechanism of two-layer microwave absorbers containing polycrystalline iron fibers and carbonyl iron, J. Magn. Magn. Mater. 331 (2013) 77-81.

[6] X.Q. Li, X.G. Feng, J.S. Gao, Optically transparent band-pass frequency selective surface, Acta Phys. Sin-Ch. Ed. 57 (2008) 3193-3197.

[7] F.C. Smith, Design principles of broadband adaptive Salisbury screen absorber, Electron. Lett. 38 (2002) 1052-1054.

[8] L.J. Du Toit, The design of Jaumann absorbers, IEEE Trans. Antennas Propag. 36 (1994) 6.

[9] H.F. Harmuth, On the effect of absorbing materials on electromagnetic waves with large relative bandwidth, IEEE Trans. Electromagn. Compat. 25 (1983) 32-39.

[10] M. D'Amore, V. De Santis, M. Feliziani, Equivalent Circuit Modeling of Frequency-Selective Surfaces Based on Nanostructured Transparent Thin Films, IEEE Trans. Magn. 48 (2012) 703-706.