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A new electromagnetic functional material composed of metallic hollow micro-spheres

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Abstract: This paper presents a new electromagnetic functional material developed by electron-less nickel deposition technique, with a single hollow micro-sphere as the core template and a thin nickel layer as the shell. The micrograph taken by a scanning electron microscope shows the microstructures of the materials in detail. Scattering parameters of the waveguide sample holder filled with the materials have been obtained over X band. The electromagnetic parameters computed from the measured S parameters show that the material with metallic hollow spheres has as high relative permeability μ_r' as 19.0 with about 0.6 magnetic loss tangent over the whole bandwidth. Compared to the material with non-metallic spheres, the permeability μ_r' and the magnetic loss tangent μ_r'' increase greatly, while the permittivity remains lower than 1.8.

Key words: electromagnetic functional material; microwave absorbing; electron-less deposition

Microwave absorbing coatings have been playing an important role in many fields such as radar cross section (RCS) reduction, EMI/EMC. In view of applications, these coatings not only need to exhibit a low reflection coefficient over a wide frequency range, but also need to be lightweight and thin. Many researches focusing on coating designs have been carried out (e.g., Salisbury, graded index, Dallenbach screen[1,2]). Some techniques have been developed in optimization of multi-layers, investigating the tradeoff between the thickness (or weight) and reflectivity[3]. Thickness and corresponding electromagnetic parameters (complex relative permeability μ_r, complex relative permittivity ε_r) of each layer are two key factors which can be determined theoretically by the optimizing design. The researches[1] show that layer materials with higher μ_r', μ_r'', ε_r'' and a small ε_r' are often required to shorten the thickness and reduce the reflectivity of the coating over a wide frequency bandwidth. Iron and ferrite powders with micro diameters as well as alloy particles of FeNi have been widely used as basic absorbing materials for coating layers[4].

This paper presents a new electromagnetic functional material as a choice for the basic materials, which have been developed by electron-less nickel deposition technique[5], with a single hollow micro-sphere as the core template and a thin nickel layer as the shell. The micrograph taken by a scanning electron microscope shows the microstructures of the material in detail. The material sample composed of the particles has been tested in an X band rectangular waveguide sample holder by a microwave vector network analyzer. The electromagnetic parameters computed from the measured S parameters are described graphically. The results show that the material has a very high μ_r' with a great magnetic loss over the whole bandwidth. The material can be used in microwave absorbing coating as basic material for some layers.

1 Materials

The investigated composite material was developed by an electron-less nickel deposition technique, which had a single hollow micro-sphere as the solution to create catalytic sites on the surfaces. Then, electron-less nickel plating on the surfaces of hollow micro-spheres,which contained Si, Al and O, was initiated by introducing the activated micro-spheres into an electron-less plating solution mainly containing nickel sulfate and formaldehyde at 85 ℃. Thus, the hollow spheres were coated with a uniform nickel film and core-shell structured material was fabricated.

The morphology of hollow micro-spheres and

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nickel-coated product shown in Fig.1 and Fig.2, respectively was characterized on a Leone 1550 type scanning electron microscope. The size of hollow micro-spheres is in the range of 0.5 μm to 10 μm. It is obvious that the metal-coated product resembles the core's morphology and its thin metal coating is very uniform and closely packed by in situ produced nano-sized nickel particles. Cross-section analysis shows that both the core wall and the shell layer are several hundred nanometers thick.

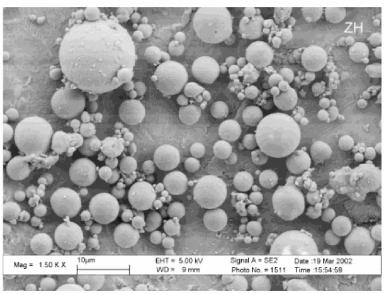

Fig.1 SEM image of hollow micro-spheres

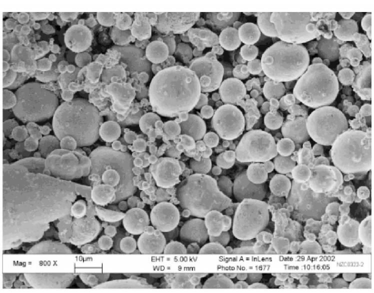

Fig.2 SEM image of nickel coated product

2 Electromagnetic Parameters and Measurements

Many techniques are applied to measure the electromagnetic parameters of loss materials such as the waveguide method, cavity method and free space method[6]. The waveguide method adopted here is described below. The powder of the material is dispersed in paraffin wax ($\varepsilon_r = 1.5$) with a volume loading of about 60%. The composite was then pressed to a waveguide framework sample holder with a flange. The inner cross section of the waveguide framework is 22.86 mm × 10.16 mm. Two waveguide-coaxial transition adaptors are adopted to connect the waveguide test framework to the vector network analyzer with coaxial interfaces. The loss material under test will cause several high order modes in the waveguide sample holder. To diminish the due influence on the test, a segment of waveguide with 100 mm length is inserted between the test framework and the transition adapter. During the error calibrations, the two sides of the framework are set as the two calibration planes. The decrease of the thickness of the framework can be helpful to reduce the high mode effect and avoid the interference of the multi values when computing the complex permeability and permittivity. The framework is only 2 mm thick.

The sample holder filled with the material under test is equivalent to a two port network simply composed of a segment of loss transmission line with characteristic impedance Z_e and transmission constant γ. The values of Z_e and γ are dependent on the complex permeability and permittivity[7,8] according to the following equations.

$$\gamma = \frac{2\pi}{\lambda_0}\sqrt{\varepsilon_r \mu_r - \left(\frac{\lambda_0}{\lambda_c}\right)^2} \quad (1)$$

$$Z_e = \frac{Z_T}{\sqrt{1 - \frac{1}{\varepsilon_r \mu_r}\left(\frac{\lambda_0}{\lambda_c}\right)^2}} \quad (2)$$

where λ_0 is the wavelength in free space; λ_c is the cutoff wavelength of the H_{10} mode which equals twice the width of the waveguide; Z_e is the impedance of the sample holder with loss material; Z_T is the TEM mode impedance in boundless space, full of the loss material.

The microwave vector network analyzer gives the calibrated value of magnitude and phase of the S parameters S_{11}, S_{21} of the sample holder from 8.5 GHz to 11.5 GHz (shown in Fig.3 and Fig.4).

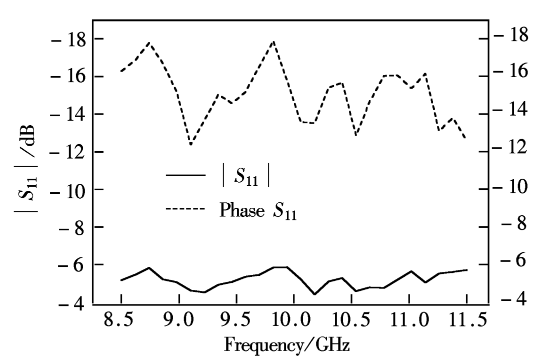

Fig.3 Magnitude and phase of S_{11}

The complex values of μ_r and ε_r can be solved by the complex transcendental equations of S_{11}, S_{21}[9] (shown in Fig.5 and Fig.6).

The computed value of the complex permeability and permittivity of the materials shows that the

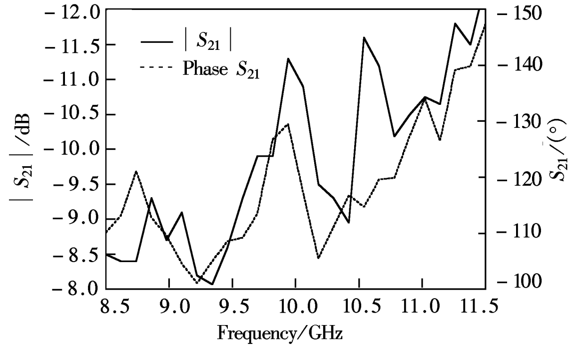

Fig.4 Magnitude and phase of S_{21}

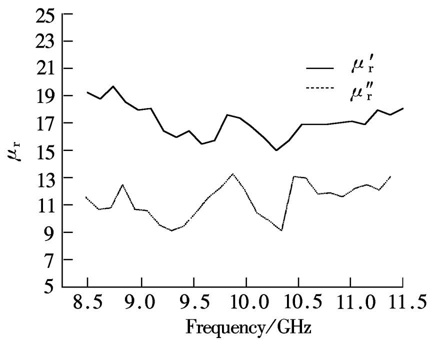

Fig.5 Computed permeability μ_r

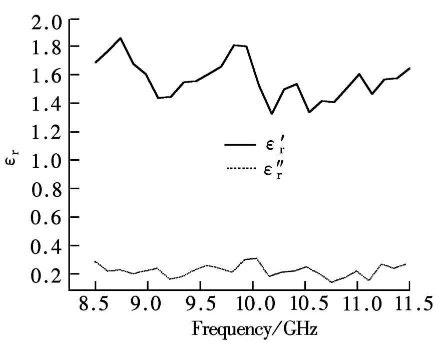

Fig.6 Computed permittivity ε_r

materials composed of metallic micro-spheres are of both electronic and magnetic loss over the frequency bandwidth from 8.5 GHz to 11.5 GHz. The real part of the permittivity reaches the maximum value 1.8 at 8.7 GHz with the electronic loss tangent 0.15. The real part of the permeability has a maximum value of 19.2 at 8.5 GHz with the imaginary part 11.4 and a magnetic loss tangent 0.6. The minimum value of the real part of the permeability is seen at 10 GHz with a value of 14.9 and a magnetic loss tangent 0.8. The variation of both permeability and permittivity is relatively slow during the whole frequency band without any obvious resonance phenomena. The test has also been carried out for the material composed of non-metallic hollow spheres. The computed μ_r and ε_r are 1.9 and 1.7, respectively, with little electromagnetic loss.

3 Conclusion

This paper presents a new material developed by electron-less nickel deposition technique, which has a single hollow micro-sphere as the core template and a thin nickel layer as the shell. The micrographs taken by a scanning electron microscope have shown the microstructures of the material in detail. The material composed of the particles is tested by microwave vector network analyzer in an X band rectangular waveguide. The electromagnetic parameters computed from the measured S parameters are presented. The results show that the material with metallic hallow spheres has a high μ_r' with a great magnetic loss over the whole bandwidth, meanwhile, the permittivity remains as low as that of the material with the non-metallic spheres. The material can be used in thin microwave absorbing coating as a basic electromagnetic functional material for some layers.

References

[1] Knott E F. The thickness criterion for single-layer radar absorbents [J]. *IEEE Trans Antennas Propag*, 1979, **27**(9):698–701.

[2] Fante R L, Michael T M. Reflection properties of the Salisbury screen[J]. *IEEE Trans Antennas Propag*, 1988, **36**(10): 1443–1454.

[3] Michielssen E, Sajer J M, Ranjthan S, et al. Design of lightweight, broad-band microwave absorbers using genetic algorithms [J]. *IEEE Tran MTT*, 1993, **41**(6):1024–1030.

[4] Ledere P, Brewitt T. Measurement of microwave properties of magnetic particulate composites [J]. *IEE Proc of Sci Meas Technol*, 2000, **147**(4):209–211.

[5] Xu Lina, Zhou Kaichang, Xu Hongfei, et al. Copper thin coating deposition on natural pollen particles[J]. *Applied Surface Science*, 2001, **183**(1/2):58–61.

[6] Juan Munoz, Marta Rojo, Alfredo Parreno, et al. Automatic measurement of permittivity and permeability at microwave frequencies using normal and oblique free-wave incidence with focused beam [J]. *IEEE Trans IM*, 1998, **47**(4):886–892.

[7] Collin R E. *Field theory of guided waves*, 2*nd Ed*.[M]. New York: McGraw-Hill, 1991.349–351.

[8] Zhang Keqian. *Electromagnetic theory for microwaves and opt electronics*[M]. Beijing: Publishing House of Electronics Industry, 2001. 197–253.(in Chinese)

[9] Nicolson A M, Ross G F. Measurement of the intrinsic properties of materials by time-domain techniques[J]. *IEEE Trans IM*, 1970, **19**(4): 77–382.

一种新型金属化空心微球电磁功能材料

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摘　要　介绍了一种新型电磁功能材料.该材料由表面无电子镀镍的空心微球组成.采用扫瞄电镜观测了镀镍前后的表面微观结构,制备成样品放入 X 波段波导框中,在微波网络分析仪上进行散射参数测量,计算了电磁特性参数.结果表明,该材料在表面镀镍后取得了较高的磁导率(19.0)和磁损耗正切(0.6),而介电常数保持较低(1.8).与非金属化微球材料相比,可作为超薄型多层微波吸收材料的基本材料.

关键词　电磁功能材料; 微波吸收; 无电子金属化

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