Study on the electromagnetic properties of a coated radar absorbent*

Zhang Shuan-Qin(张栓勤)†

The First Engineers Scientific Research Institute of Wuxi, WuXi 214035, China

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The sol–gel method is used to fabricate Fe crystalline powders coated with SiO_2. By controlling the molar ratio R of diluted water to tetraethoxysilane (TEOS), Fe powders coated with SiO_2 with different morphological characteristics are fabricated. The influence of the core diameter on electromagnetic parameters is investigated. The effect of the amount of the coating material SiO_2 on electromagnetic parameters is given. Radar wave absorbing properties of Fe coated with SiO_2 and TiO_2 respectively are compared.

Keywords: coated absorbent, effective electromagnetic coefficient

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1. Introduction

With the increasing development of radar reconnaissance and detection technology, radar absorbing material (RAM) plays an important role in reducing reflections from metallic structures. Such a material is often required to provide a specified reflectivity performance over a wide frequency range. The design is usually constrained by factors such as weight, thickness, environmental survivability, and cost. Thin, light, wideband absorbing properties, and strong mechanical ability are four properties required for RAM in the near future.[1−3]

The absorbing property of RAMs is determined mainly by their magnetic properties and dielectric properties, which can be described by the complex magnetic permeability $\mu = \mu' + \mu''$ and dielectric permittivity $\varepsilon = \varepsilon' + \varepsilon''$. For an ideal RAM which has a high absorbing property in the frequency range of interest to us, the imaginary parts of u'' and ε'' should be relatively high. u and ε can be described in the functional forms of frequency $u(\omega)$ and $\varepsilon(\omega)$ as usual. Therefore, by controlling the dielectric and the magnetic properties of RAM, the absorbing properties of RAM are determined. For most materials, they exhibit only dielectric properties. RAM with only dielectric properties can be made light, but often exhibits a narrow band absorbing property. While magnetic RAM generally has a good absorbing property, but has a high weight problem.[4−7] In Refs. [8] and [9] a good measure was proposed to increase the absorbing property of the radar absorbent.

In the present paper, magnetic absorbent is coated by the dielectric material in order to reduce the ε of the magnetic absorbent for better impedance. The core particle can be magnetic metallic powders. A thin layer of a dielectric material is coated on the magnetic core. The influences of the core diameter and the coating material on its magnetic and dielectric properties are analysed.

2. Experiment

2.1. Fabrication of the Fe coated SiO_2

The sol–gel method was used to prepare Fe powders coated with a thin layer of SiO_2 or TiO_2. Nano-Fe powders were dispersed into the mixed solution composed of tetraethoxysilane (TEOS) or tetrabutyltitanate (TBT), deionized water as the solvent, ammonia water as a base catalyst, and ethanol thoroughly. Then TEOS coated on the surface of Fe powders was hydrolyzed and polymerized. After being kept at room temperature for 3 to 4 days, gel with a Fe core was formed. The gel was sintered in N_2 atmosphere at high temperature. Fe powders coated with SiO_2 or TiO_2 were formulated finally.

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†Corresponding author. E-mail: fcwzsq@163.com

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2.2. Measurements

A scanning electron microscope (SEM) (JSM-6360-LV type made by Japan) was used to measure the morphology of the Fe powders and the Fe with SiO_2 coatings.

The Fe crystalline powders coated with SiO_2 were observed by using a high resolution transmission electron microscope (HR-TEM) (JEM-1200EX II type made by Japan).

The magnetic properties $\varepsilon(\omega)$ and $u(\omega)$ of Fe powders coated with SiO_2 were measured over a range of 2 GHz–18 GHz frequencies. Fe crystalline powders coated with SiO_2 were thoroughly mixed with paraffine wax at a weight ratio of 7:1. Then the paste was made into a round coaxial test fixture. After the solvent was thoroughly dried, an HP8510B vector network analyzer was used to measure the magnetic properties $\varepsilon(\omega)$ and $u(\omega)$ of the Fe crystalline absorbent coated with SiO_2.

3. Results and discussion

3.1. Influence of the amount of the diluted water on the gelation time

Figure 1 shows the effect of the molar ratio R of the diluted water to TEOS on gelation time. It is shown that the gelation time is shortest with R being 8. With R being less than 8, the gelation time is shortened with R increasing. With R being larger than 8, the gelation time increases with R increasing.

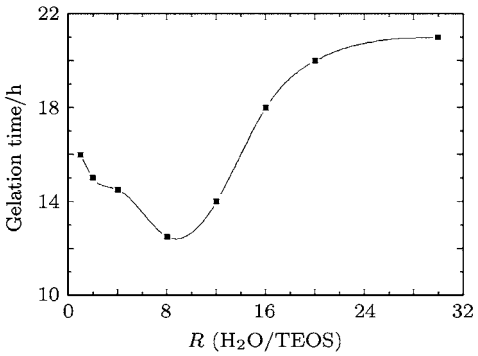


Fig. 1. Influence of the molar ratio R on the gelation time.

Also, the molar ratio R has an important influence on the morphological characteristics of Fe powders coated with SiO_2. Figure 2 shows the TEM images of Fe powders coated with a thin layer of SiO_2. It is shown that the diameters of the Fe powders coated with SiO_2 increase with R increasing. The average diameter of Fe powders coated with SiO_2 is 40 nm when R equals 50. This is due to the fact that with R increasing, the gelation time becomes longer, and the grains of Fe powders coated with SiO_2 can grow large. Also, it is shown that the grains of Fe powders coated with SiO_2 aggregate together when R is 15.

Figure 3 shows the SEM images of Fe powders coated with SiO_2. It is shown that the grains of Fe powders are completely coated with SiO_2. Also, the particles cluster together.

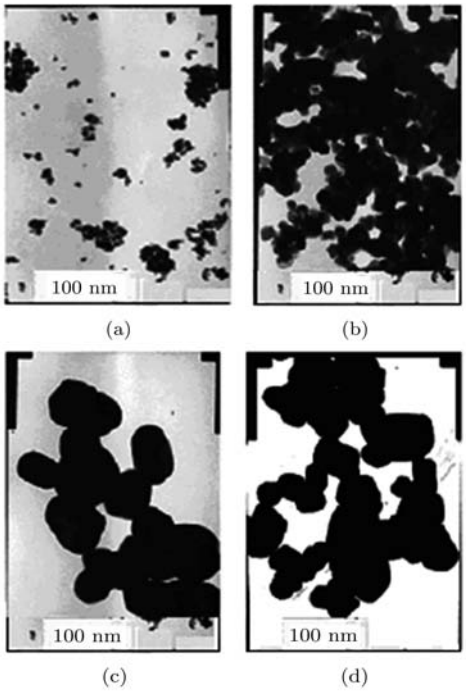


Fig. 2. Morphological characteristics of Fe powders coated with SiO_2 for different values of molar ratio R of the diluted water to TEOS: (a) $R = 5$, (b) $R = 15$, (c) $R = 30$, (d) $R = 50$.

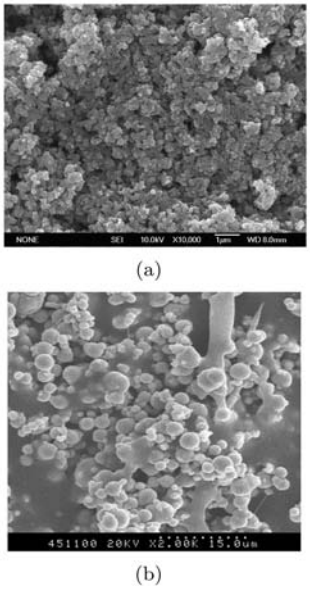


Fig. 3. SEM images of Fe powders (a) and Fe coated with SiO_2 (b).

3.2. Influence of core diameter on electromagnetic parameters

Figure 4 shows the influences of the core diameter on the electromagnetic parameters of Fe coated with SiO_2, with different core diameters. Comparing Figs. 4(a)–4(d), it is shown that ε', μ', and ε'' all decline with frequency increasing from 2 GHz to 18 GHz. μ'' varies less with frequency. When the core diameter is 29 nm, μ'' reaches a maximum at 6 GHz. With core diameter increasing to 52 nm, μ'' reaches a maximum at about 5 GHz. The analysis shows that the maximal value of μ'' results from the ferromagnetic resonance effect. Also the ferromagnetic resonance effect shifts toward lower frequency with the increase of core diameter.[8−10]

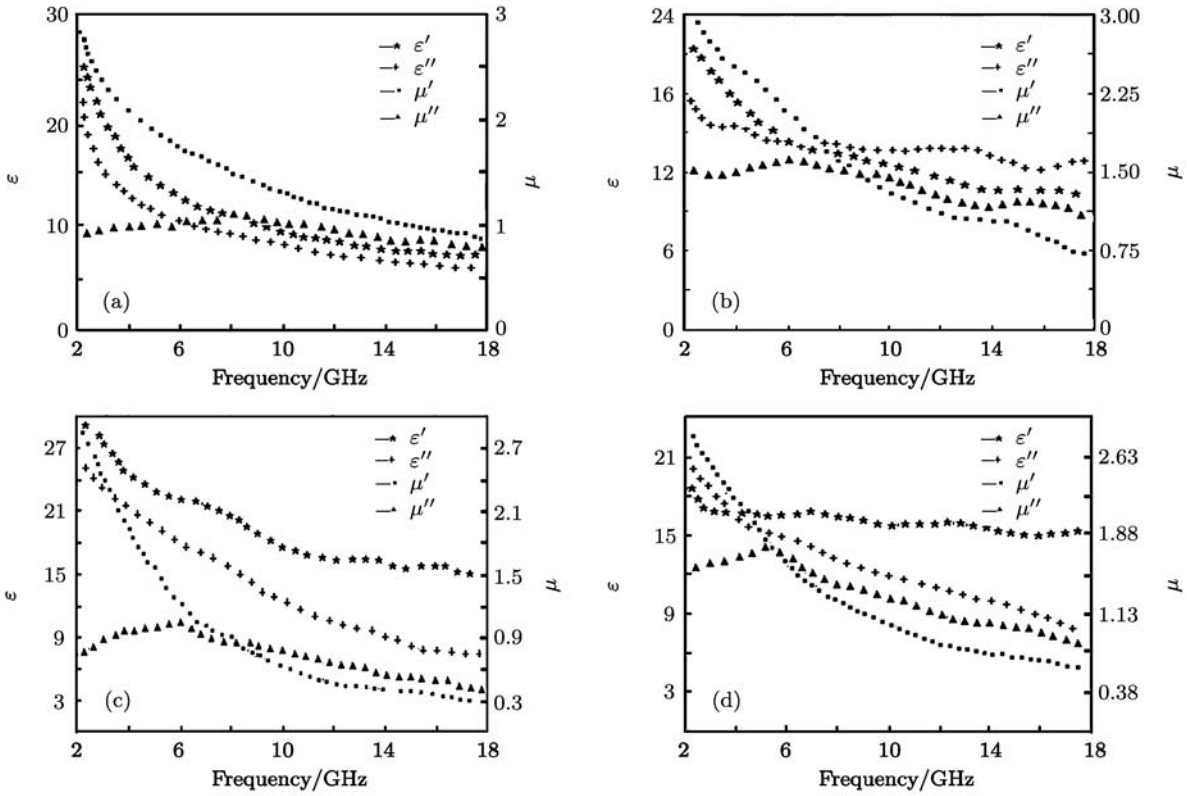


Fig. 4. Frequency-dependent electromagnetic parameters of Fe powders coated with SiO_2, with core diameters being 12 (a), 18 (b), 29 (c), and 52 nm (d).

3.3. Influence of the amount of the coating material on electromagnetic parameters

Figure 5 shows the influence of the amount of the coating material on electromagnetic parameters. The amounts of the coating material SiO_2 are 15% and 25% respectively according to the weight ratio. The values of ε'' and μ'' vary less while the values of ε' and μ' decline with the amount of the coating material SiO_2 increasing.

3.4. Influence of coating material on electromagnetic properties

Table 1 shows the measured saturation magnetizations of the absorbent for different coating materials (SiO_2 and TiO_2) respectively.

Table 1. Saturation magnetization of absorbent for different coating materials (SiO_2 and TiO_2).

Sample	Fe	Fe/SiO_2	Fe/TiO_2
Measured saturation magnetization/$A \cdot m^{-1}$	325.5	166.7	222.7

It is shown that the saturation magnetization of the nano-Fe absorbent is higher than that of the SiO_2-coated Fe absorbent. While Fe samples coated separately with SiO_2 and TiO_2 have different saturation magnetizations. The saturation magnetization of Fe coated with SiO_2 decreases greatly compared with that of nano-Fe absorbent in the same conditions. While different coating materials as SiO_2 and TiO_2 will influence the saturation magnetization of coated Fe absorbent.

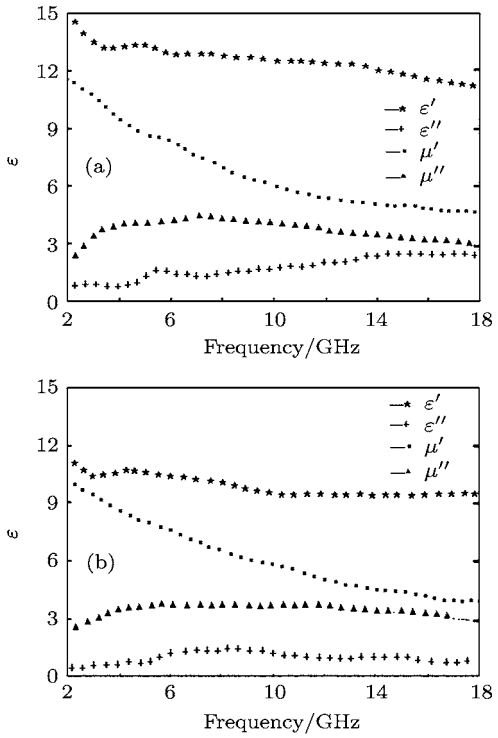


Fig. 5. Influences of the amount of coating material on the electromagnetic parameters. The amounts of the coating SiO_2 are 15% (a) and 25% (b).

Figure 6 shows that the computed absorbing properties of SiO_2- and TiO_2-coated Fe absorbents versus frequency. SiO_2-coated Fe absorbent has a strong absorbing peak around 18 GHz; while the absorbing peak of TiO_2-coated Fe absorbent is around 12 GHz. Therefore using different materials to coat an Fe absorbent is a good way to change its electromagnetic properties.

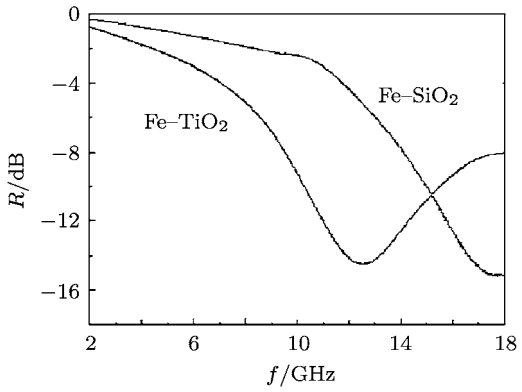


Fig. 6. Radar absorbing properties versus frequency.

4. Conclusion

Fe coated with SiO_2 is fabricated by using the sol–gel method. By controlling the molar ratio R of the diluted water to TEOS, Fe powders coated with SiO_2, with different morphological characteristics, are fabricated. The influence of the core diameter on the electromagnetic parameters is analysed. With the core diameter increasing to 52 nm, μ'' reaches a maximum at about 5 GHz. The effect of the amount of the coating material SiO_2 on the electromagnetic parameters is investigated. The values of ε'' and μ'' vary less, while the values of $\varepsilon\prime$ and $\mu\prime$ decline with the amount of the coating material SiO_2 increasing. The saturation magnetization of Fe coated with SiO_2 is less than that of the Fe coated with TiO_2. The computed absorbing properties of the coated Fe absorbent varying with frequency are given, showing that a magnetic absorbent coated with a suitable dielectric material can improve its electromagnetic properties greatly.

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