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Original Research Paper

Facile synthesis and enhanced electromagnetic wave absorption of thorny-like Fe–Ni alloy/ordered mesoporous carbon composite

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ABSTRACT

Ordered mesoporous carbon (OMC) coated with thorny-like Fe–Ni alloy composites have been successfully synthesized. The electromagnetic (EM) parameters of Fe–Ni alloy/OMC/paraffin wax composites were measured. Interestingly, the μ'' values of Fe–Ni(0.2)/OMC were very negative from ~7 to 18 GHz and the minimum value was −0.7, which are mainly caused by the eddy current. The reflection loss (RL) values were calculated with the measured EM parameters based on the transmission line theory. Results showed that the effective absorption bandwidth (<−10 dB) of Fe–Ni(0.2)/OMC/paraffin wax composites with the thickness of 2.00 mm could reach up to 4.8 GHz. The enhanced EM wave-absorbing properties of the composites could be attributed to well impedance matching between the absorber and air. Moreover, the enhanced dielectric loss and magnetic loss induced by Fe–Ni alloy also played a crucial role in the EM wave-absorbing process.

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1. Introduction

In recent years, electromagnetic (EM) wave-absorbing materials have received considerable attention due to the increasing of EM wave pollution in gigahertz (GHz) range [1–3]. It is well known that an ideal EM wave absorber should have a series of significant characteristics, such as thin thickness, broad effective absorption bandwidth (Δf_{eff}, RL < −10 dB), low density, and high reflection loss (RL). Generally, the relative complex permittivity ($\varepsilon_r = \varepsilon' - j\varepsilon''$) and permeability ($\mu_r = \mu' - j\mu''$) of the absorber need to utmost close to that of air in order to let most of the EM wave enter the absorber, as is called as impedance matching characteristic. Additionally, high dielectric loss ($\tan\delta_\varepsilon = \varepsilon''/\varepsilon'$) and magnetic loss ($\tan\delta_\mu = \mu''/\mu'$) capacities are essential in order to attenuate the EM energy to a great extent subsequently.

Owing to high specific surface area, tunable pore size and periodic pore arrangement, the ordered mesoporous carbon (OMC) has been widely investigated in modern technology and its applications range from photocatalysis to energy storage, etc. [4–7]. OMC is also a promising EM wave-absorbing materials closely related to its ordered microstructure [8]. Firstly, the porous periodic structure is definitely in favor of the reduction of the density as well as the declination of complex permittivity. As a result, the vast majority of EM wave can enter OMC. Secondly, the ordered and parallel pore walls can bring multiple-reflection to the incident EM waves, leading to further enhancement of EM wave absorption. However, OMC is a typical dielectric loss material and lack of magnetic loss is a great limitation for its further application as EM wave absorbers. Magnetic materials, such as Fe, Ni, Co and their alloys, are suitable for the EM wave absorbents for their higher saturation magnetization and permeability [9]. For example, it is reported that Fe–50 wt.%Ni alloy exhibits adjustable microwave-absorbing properties in the range of 1–18 GHz [10] and the Δf_{eff} of $FeNi_3$/epoxy composite with the thickness of 1.60 mm can reach 3.6 GHz [11]. The EM properties of flake Fe–Co–Zr alloy of which the surface is modified have also been reported elsewhere [12]. However, the magnetic materials still have some drawbacks in EM properties, such as mismatching EM parameters, high density and high mass filling percentage. The combination of OMC together with magnetic materials may be an efficient strategy to fully make use of the respective advantages of them. Some tentative work has been done, such as γ-Fe_2O_3/C, Ni_2O_3/OMC and C-Al_2O_3. The EM wave-absorbing properties of OMC supported by Au and Ag nanoparticles have also been investigated in our previous researches [13–16]. Experimental results confirmed that the combination of OMC and metal components contributed to the enhanced EM wave absorption.

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Up to now, the vast majority of the researches were focused on the OMC-based composites of which the channels are partly filled with some metal or oxide components, but few are reported in the field of metal alloy-coated OMC composites. Since previous report [17] showed that the EM wave-absorbing property of composites is remarkably affected by the shape and microstructure of the absorber, in present paper, we try to synthesize a composite of OMC coated with three-dimensional (3D) thorny-like Fe–Ni alloy by a facile but reliable method. Subsequently, the EM parameters of Fe–Ni alloy/OMC/paraffin wax composites were measured. Based on the measured EM parameters and the transmission line theory, the RL of the composites could be calculated. The results showed that the Δf_{eff} of the as-synthesized Fe–Ni(0.2)/OMC/paraffin wax composites with the thickness of 2.00 mm could reach up to 4.8 GHz, indicating that the composite is a promising candidate for high-efficiency EM wave absorber.

2. Experimental

2.1. Synthesis of OMC

OMC was synthesized by using triblock copolymer F127 and soluble phenolic resin as a structure-directing agent and carbon sources, respectively [18]. Typically, 1.22 g phenol was melted at 50 °C, then 0.22 g NaOH (20 wt.%) aqueous solution was added slowly, followed by the addition of 2.09 g formaldehyde (37 wt.%) at 75 °C and held for 1.5 h with a reflux condenser to form the resol solution. Meanwhile, 1.97 g F127 was dissolved into 30 g ethanol under magnetic stirring at 35 °C. Then, the resol solution, which was adjusted to neutral (7.0) by 0.6 M HCl, was added slowly into the above solution and followed by 1 h continuously stirring. The obtained solution was poured into several dishes to evaporate the ethanol at room temperature overnight, followed by solidification in an oven at 100 °C for 24 h. The as-prepared products were

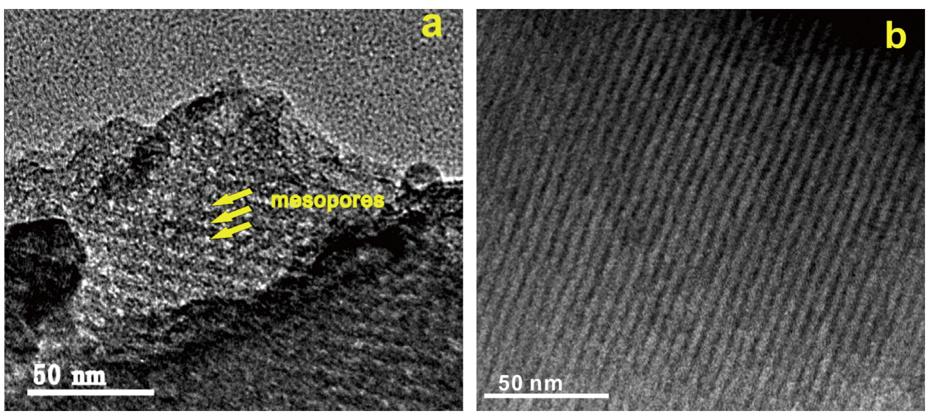

Fig. 1. TEM images of OMC.

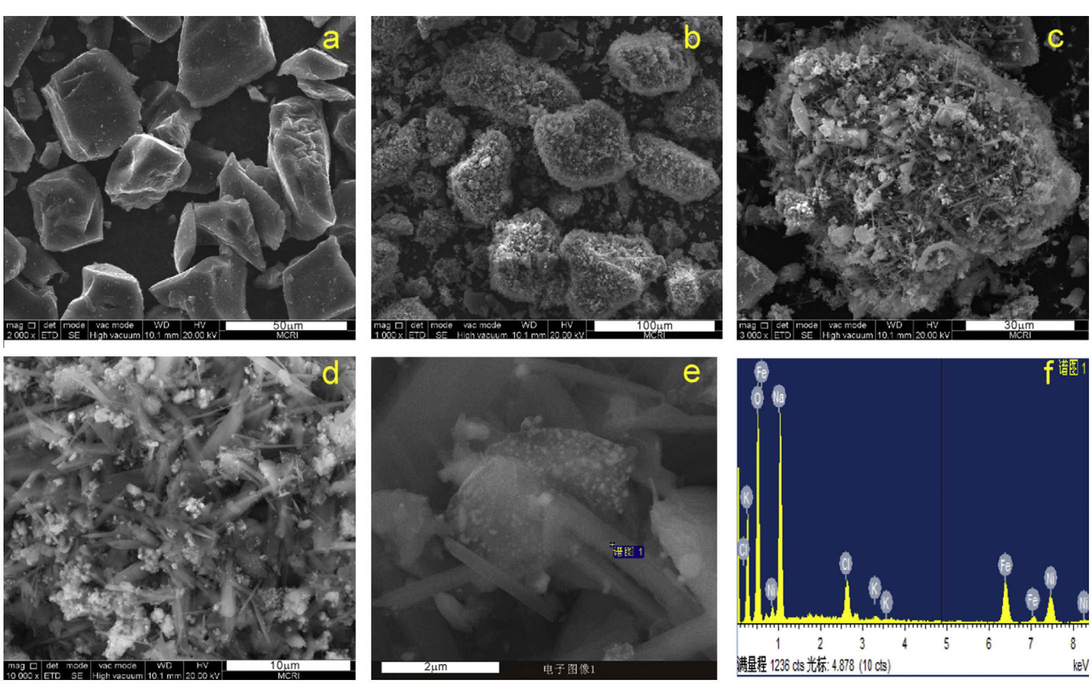

Fig. 2. SEM images for (a) pure OMC and (b) Fe–Ni(0.2)/OMC. Magnified images(c–e) and EDS spectrum (f) for thorny-like Fe–Ni alloy.

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