Applied Surface Science 445 (2018) 82–88

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Full Length Article

Facile synthesis of Fe_3O_4/C composites for broadband microwave absorption properties

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ARTICLE INFO

Article history:
Received 5 July 2017
Revised 20 February 2018
Accepted 16 March 2018
Available online 20 March 2018

Keywords:
Microwave absorption
Magnetite
Permeability
Permittivity

ABSTRACT

Rod-like and flower-like Fe_3O_4/C composites were successfully synthesized via a facile approach in aqueous phase. The morphologies, structures and static magnetic properties of as-prepared rod-like and flower-like Fe_3O_4/C composites were characterized thoroughly. The relative complex permittivity and permeability of Fe_3O_4/C/paraffin composites were recorded by a vector network analyzer (VNA) in the range of 1–18 GHz. The resonant-antiresonant electromagnetic behavior was observed simultaneously in both rod-like and flower-like Fe_3O_4/C composites. Moreover, the resonant-antiresonant behavior was explained using displacement current lag at the "core/shell" interface. The flower-like Fe_3O_4/C/paraffin composites show superior microwave absorption performance with minimum reflection loss (*RL*) of up to −18.73 dB at 15.37 GHz. Comparatively, the rod-like Fe_3O_4/C/paraffin composites have uncommon continuous trinal absorption peaks at a thickness of 2.5 mm that effectively broadens the absorption bandwidth which is from 8.0 to 13.4 GHz. Furthermore, the microwave absorption mechanism has been discussed to provide a novel design for microwave absorption materials.

1. Introduction

Electromagnetic (EM) wave absorption materials with features of "low density, strong absorption and wide bandwidth" have become cutting-edge issues in wireless communication for civilian and stealth materials for the military [1–10]. Magnetic/dielectric composite materials with outstanding magnetic properties and good impedance matching in GHz range have gained much attention of researchers [11–15]. Among the magnetic materials, the iron oxides are more particularly intriguing due to their strong magnetic moment, related earth abundance, easy to prepare, non-toxicity and low cost [16–22]. Meanwhile, carbon material decorated with iron oxides could further improve the impedance matching and microwave absorption intensity [23–28]. Therefore, the strong absorption characteristics and broadband absorption properties make Fe_3O_4/C composites popularity as microwave absorber [29–35].

According to the transmission line model, the reflection loss (RL) of absorber backed metal plate can be simulated as follow [36–38]:

$$RL = 20\log|(Z_{in} - 1)/(Z_{in} + 1)| \tag{1}$$

$$Z_{in} = (\mu_r/\varepsilon_r)^{1/2} \tanh[j(2\pi fd/c)(\mu_r\varepsilon_r)^{1/2}] \tag{2}$$

where *RL* is reflection loss coefficient, Z_{in} is normalized input impedance, μ_r and ε_r are the relative complex permeability and permittivity of the absorber at frequency (*f*), c is the velocity of microwave wave in free space, and *d* is the thickness of absorber. The microwave absorption properties are closely related to electromagnetic parameters, the complex permittivity ($\varepsilon_r = \varepsilon' - j\varepsilon''$) and the complex permeability ($\mu_r = \mu' - j\mu''$). The real parts of complex permittivity and permeability stand for energy storage while the image parts stand for energy dissipation. It is well-known that the electromagnetic parameters of absorbers in GHz range closely depend on their size distribution and shape anisotropy [39–41]. Magnetite 1D nanowires [18], hierarchical dendrites [19], microspheres [42], and nanorods [43] have been extensively studied on revealing the dependency of microwave performance on the morphology. Penn et al. discussed the effect of porosity and grain size on the microwave dielectric properties [44]. Yang et al. found that larger diameter lead to a high permittivity, low permeability and higher resonance frequency as a consequence of stronger shape anisotropy [21]. She et al. proposed a reliable strategy to tune the electromagnetic parameters via different aspect ratio polymer@α-MnO_2 microspindles [40]. In the Eq. (2), apart from the relative complex permeability and permittivity, the thickness of absorber is also a key factor in enhancing microwave absorption properties. Moreover, microwave at GHz range is

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https://doi.org/10.1016/j.apsusc.2018.03.127
0169-4332/

millimeter wave which is close to dimensions of absorber thickness. Wang et al. investigated the quarter-wavelength cancellation in single layer absorber for flake-shaped carbonyl-iron particle composite [45]. Microwave energy could be sharp attenuation when the thickness is equal to a quarter-wavelength of traveling microwave and it could explain the characteristics of *RL* peaks well, such as the presence of dual peaks and peak positions [46]. Meanwhile, to obtain good impedance matching and broadband attenuation microwave absorbers are still complex and full of challenge.

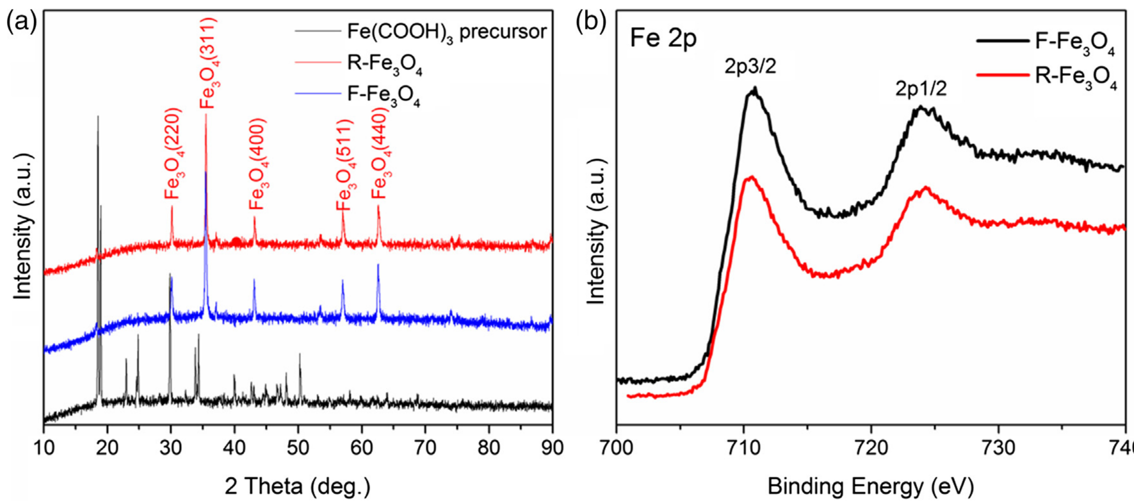

Fig. 1. (a) XRD patterns of $Fe(COOH)_3$ precursor, flower-like and rod-like Fe_3O_4/C composites, (b) Fe 2p core-level XPS spectra of the as-prepared samples.

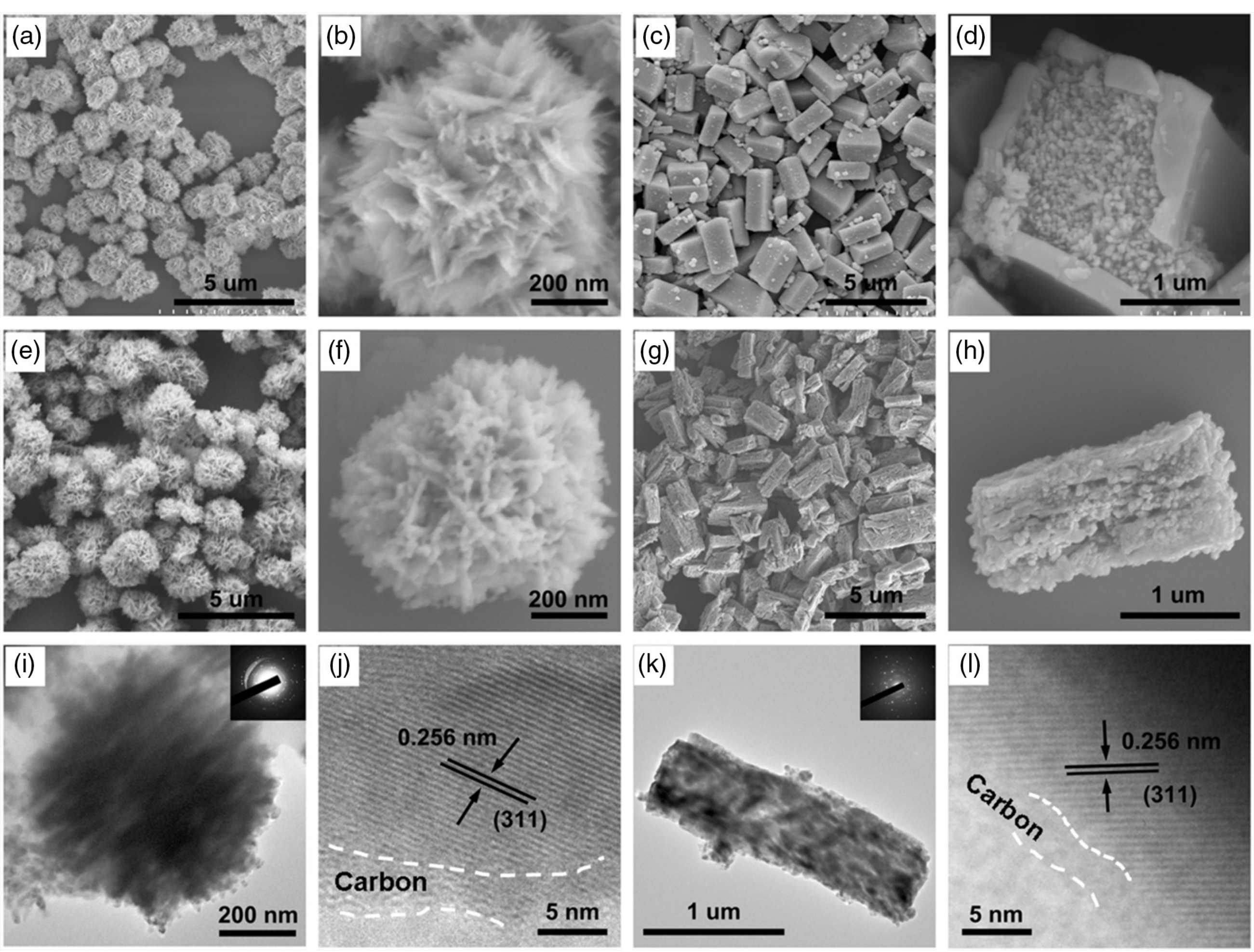

Fig. 2. The SEM micrographs of flower-like (a–b) and rod-like precursors (c–d), counterpart (e–f) and (g–h) after heat treating, the TEM images of single F-Fe_3O_4 (i) and R-Fe_3O_4 (k), insets are corresponding SAED patterns, HRTEM images of F-Fe_3O_4 (j) and R-Fe_3O_4 (l).