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Enhanced electromagnetic absorption properties of carbon nanotubes and zinc oxide whisker microwave absorber

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ABSTRACT

CNTs/ZnOw composites were fabricated by a simple mechanical mixing method. The effects of the different CNTs and ZnOw mass fractions on the electromagnetic parameters and wave absorbing properties of the composites were studied. The complex permittivity and attenuation constant increase with increasing mass fractions of CNTs and ZnOw. However, the microwave impedance decreases with the increasing concentrations of CNTs and ZnOw. The experimental results show that 4 wt% CNTs mixed with 10 wt% ZnOw has the optimum microwave absorption ability with a thickness of 2.0 mm. The minimum reflection loss is −37.03 dB at 12.24 GHz and the bandwidth corresponding to the reflection loss below −10 dB is more than 4.04 GHz. Compared with pure CNTs or ZnOw, it cannot only greatly reduce the mass fractions of microwave absorbing materials, but also enhance the microwave absorption properties. The results indicate that the prepared CNTs/ZnOw composites have excellent absorbing properties with thin thickness and lightweight.

1. Introduction

In recent decades, the microwave absorbing materials have attracted considerable interest in both commercial and military purposes. The microwave absorbing materials can be used to minimize the electromagnetic reflection from the metal plate such as aircrafts, ships, tanks and the walls of an echoic chambers and electronic equipments [1–4]. Extensive studies have been carried out to find suitable microwave absorbers [5–7]. Ferrites [8–12] and carbonyl iron [13–15] have been utilized as absorbing materials in various forms due to their large magnetic loss and large resistivity. However, unavoidable disadvantage of overweight of these magnetic absorbers has greatly limited the applications. Much effort has been devoted to the development of better radar absorbing materials with lightweight, thin thickness and wide band absorption [16–18].

Compared with magnetic absorbers, the dielectric absorbers are relatively of low density for their low mixing ratios, which are more suitable for radar absorbing materials with light weight and thin thickness. Since the discovery in 1991 [19], carbon nanotubes (CNTs) have been widely studied as microwave absorbing materials for higher aspect ratio and electrical conductivity. The concentration of CNTs is extremely important for the application as microwave absorbing material. A certain amount of CNTs is required for the attenuation of the microwave, however, a low loading is expected to avoid or minimize the degradation of other performance aspects, such as the mechanical properties [20]. Zinc oxide whisker (ZnOw) is comprised of a central part and four needle crystal projections extending from said part in plural different axial directions [21], has shown great potential as radar absorbing material [21–25]. On the basis of these characteristics, novel electromagnetic wave absorption properties are expected from the combination of ZnOw and CNTs. Li et al. [26] revealed the CNTs/T–ZnO/EP composite exhibited excellent microwave absorption properties compared with CNTs/EP and T–ZnO/EP composites. A minimum reflection loss of −23.00 dB were obtained when the content of CNTs and T–ZnO are 12 wt% and 8 wt%, respectively. However, further studies are still necessary to optimize the mass fraction of CNTs and ZnOw for a better microwave absorbing ability. Furthermore, a high concentration of CNTs in the composites is expected to be avoided, which will result in degradation of other performance.

In the present work, CNTs/ZnOw composites were fabricated by a simple mechanical mixing method. The effects of the different concentrations of CNTs and ZnOw on the electromagnetic parameters and microwave absorbing properties of the composites were studied. The optimization of CNTs and ZnOw concentrations

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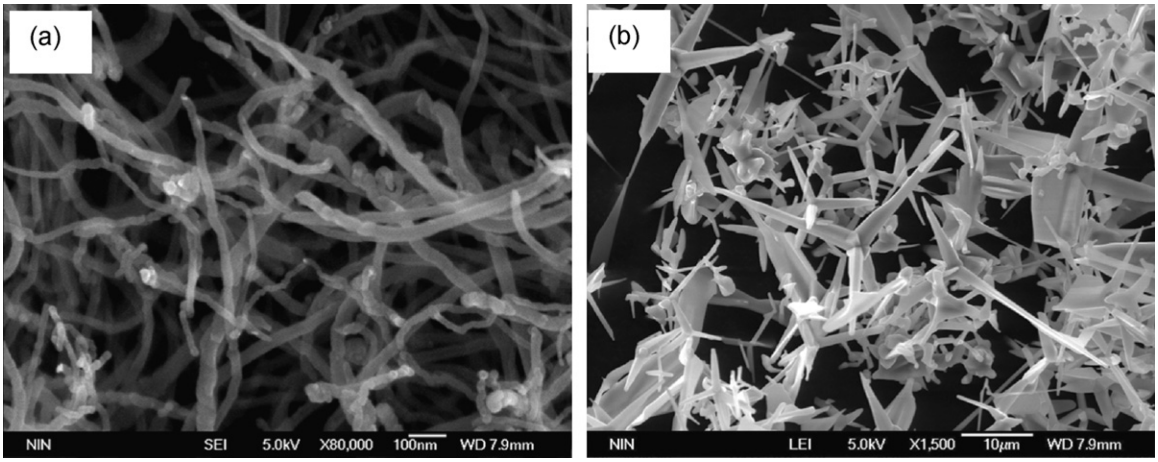

Fig. 1. Scanning electron microscopy (SEM) of CNTs (a) and ZnOw (b).

was realized. The results show that optimized composite possesses excellent microwave absorbing property.

2. Experimental

Multi-walled carbon nanotubes were synthesized by chemical vapor deposition with diameters ranging from 5 to 15 nm and lengths ranging from 10 to 20 μm. The surface morphology of CNTs was examined by scanning electron microscopy (JSM-6700), which is shown in Fig. 1(a). ZnOw were synthesized with equilibrant reaction method. Details of the preparation method were described elsewhere [27]. The length and basal diameter of the needles of the whiskers were 15–120 μm and 1.8–6.6 μm, respectively (Fig. 1(b)).

The CNTs/ZnOw complex absorbers were obtained by homogeneously mixing the CNTs and ZnOw with various weight fractions instead of the complicated chemical methods devices. Therefore, this method is in close relation to industry processes. For measurements of the electromagnetic parameters, CNTs/ZnOw complex absorbers were mixed with paraffin and poured into coaxial clapper in a dimension of outer diameter of 7.0 mm, inner diameter of 3.0 mm, respectively. The proportions of each component are shown in Table 1. The complex permittivity $\varepsilon_r(f)$ and permeability $\mu_r(f)$ of CNTs/ZnOw composites were measured by the T/R coaxial line method in the frequency range of 2–18 GHz using a network analyze (Agilent technologies E8362B:10 MHz–20 GHz). The microwave absorbing performances were evaluated by the following equation [28]:

$$R = 20\log\left|\frac{Z_{\rm in} - Z_0}{Z_{\rm in} + Z_0}\right| \tag{1}$$

where R denotes the reflection loss in dB unit. Z_0 is the characteristic impedance of free space. $Z_{\rm in}$ is the input characteristic impedance at the absorber/free space interface, which can be expressed as

$$Z_{\rm in} = Z_0\sqrt{\frac{\mu_r}{\varepsilon_r}}\tan h\left(j\left(\frac{2\pi f d}{c}\right)\sqrt{\mu_r\varepsilon_r}\right) \tag{2}$$

where c is the velocity of light, f is the frequency of electromagnetic wave, d is the thickness of an absorber. In this paper, all d values are in mm unit. $\varepsilon_r = \varepsilon' - j\varepsilon''$ is complex permittivity, $\mu_r = \mu' - j\mu''$ is complex permeability.

Table 1
Proportion of the components of the samples.

Samples	CNTs (wt%)	ZnOw (wt%)
1	4%	0%
2	6%	0%
3	8%	0%
4	10%	0%
5	0%	15%
6	2%	15%
7	4%	15%
8	6%	15%
9	8%	15%
10	4%	5%
11	4%	10%
12	4%	20%
13	4%	30%

3. Results and discussion

3.1. Electromagnetic and absorbing properties of CNTs

Fig. 2 shows the real and imaginary parts of complex permittivity of CNTs/paraffin with four concentrations (4, 6, 8 and 10 wt%) in the frequency range of 2–18 GHz. The real and imaginary parts of complex permittivity of the CNTs samples show a similar variety trend. With increasing frequency, the values of real part of complex permittivity decrease slightly. It can be noticed that the higher is the CNTs weight percent addition, the greater are both the real and imaginary permittivity in the frequency range of 2–12 GHz. Increase of the real part of the complex permittivity can be mainly ascribed to dielectric relaxation and space charge polarization effect, whereas an increase of the imaginary part of the complex permittivity can be attributed to the enhanced electrical conductivity of the material [29].

In order to further characterize the absorbing performances of the CNTs with different mass fractions, the reflection loss of CNTs absorbents were calculated based on Eqs. (1) and (2). Fig. 3 shows variation of the reflection loss versus frequency of CNTs absorbents with a constant thickness (2.0 mm) in the frequency range of 2–18 GHz. With increasing of CNTs contents, the microwave absorption peak firstly increases then decreases. The reflection loss reaches a minimum of −18.06 dB with 6 wt% CNTs, and the minimum reflection loss decreased to −13.9 dB and −5.4 dB with the increasing contents of the CNTs (8 and 10 wt%), respectively. Additionally, when it is related to same thickness the values of reflection loss shift to lower frequency with increasing contents of CNTs.

3.2. Effect of CNTs concentration on electromagnetic and absorbing properties of CNTs/ZnOw composites

The CNTs/ZnOw complex absorbers were obtained by homogeneously mixing the CNTs and ZnOw with various weight fractions (sample 5#, 6#, 7#, 8# and 9#). The weight content of ZnOw was 15 wt%, and the weight content of CNTs ranged from 0 wt% to 8 wt%. We hope that the combination of ZnOw and CNTs will improve the microwave absorption properties of CNTs/ZnOw composites. Moreover, the effect of CNTs concentrations on electromagnetic and absorbing properties of CNTs/ZnOw composites was also greatly expected.

Fig. 4 shows the real and imaginary parts of permittivity of CNTs/ZnOw composites. It can be seen from Fig. 4(a) that the real part of complex permittivity of ZnOw remains nearly constant (2.7).