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Synthesis of Fe_3O_4 hollow nanospheres-carbon nanotubes nanocomposites for the enhancement of dielectric heating performance

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ABSTRACT

Fe_3O_4 hollow nanospheres-carbon nanotubes (Fe_3O_4 HNSs-CNTs) nanocomposites were synthesized under one-pot solvothermal treatment. The crystalline structure, size and morphology of the composite products are characterized by XRD, SEM and TEM, indicating that Fe_3O_4 HNSs are tightly wrapped by CNTs with a good distribution. The products were dispersed in silicone oil for evaluating the dielectric heating performance under microwave irradiation. The Fe_3O_4 HNSs-CNTs nanocomposite (mass ratio 1:9) exhibits the best dielectric heating performance under microwave irradiation among all products, probably because an optimized proportion of Fe_3O_4 HNSs can improve the joint heating effect where the Fe_3O_4 HNSs as bridges between CNTs strengthen the interfacial polarization. The nanocomposites can be totally separated from the liquid medium by magnetic decantation.

1. Introduction

The materials sensitive to dielectric heating can effectively absorb the electromagnetic waves and convert them into heating, which leads to the rapid temperature increasing [1–3]. These materials include metal particles [4], ferromagnetic compounds [5], and carbon nanomaterials [6], which have been reported for many interesting applications (e.g. microwave absorption, hyperthermia therapy, pollutant degradation, reworkable adhesives) [3–10]. The major sources for dielectric heating include microwave and radio frequency, among which the microwave can achieve highly selective, instantaneous volumetric heating [11]. Dipolar, electric, and magnetic loss are the three main routes to contribute the microwave-induced heating [4,6,12,13]. Materials types and morphologies should also be considered as important factors affecting the dielectric heating performance [5,8,10,13].

Previous works demonstrated that Fe_3O_4 and carbon nanotubes (CNTs) showed good dielectric heating efficiency [5,6] and potential application for cancer treatment under hyperthermia therapy [7,8]. Fe_3O_4 with hollow spherical morphology exhibiting better heating performance was reported for the degradation of reworkable nanocomposite adhesives to disassemble adhesive joints [10]. Furthermore, carbon nanotubes (CNTs) exhibited excellent dielectric heating performance as the temperature $\geq$ 1500 °C was observed in microwave fields [3,6,13]. However, the application of CNTs is restricted due to the difficulty in target heating and recycling. Fe_3O_4 hollow nanospheres (HNSs) can be easily positioned and separated in the magnetic field, but the joint dielectric heating of Fe_3O_4 HNSs-CNTs is seldom investigated.

In this work, we report a one-pot route for the synthesis of Fe_3O_4 HNSs-CNTs nanocomposites. Characterization results show that the Fe_3O_4 HNSs are tightly wrapped by CNTs with a good distribution. The dielectric heating performance is evaluated under microwave at 2.45 GHz by dispersing the as-prepared nanocomposites in liquid heating medium of silicone oil. The Fe_3O_4 HNSs-CNTs nanocomposite (mass ratio 1:9) not only shows the optimum dielectric heating performance but also can be totally separated from the liquid heating medium by magnetic decantation.

2. Experimental details

In a typical procedure, 0.450 g of CNTs (multi-walled, O.D. × L 6–9 nm × 5 μm) were dispersed in 60 mL ethylene glycol under sonication at 50 °C. 0.729 g of cetyltrimethylammonium bromide (CTAB) and 0.701 g of hexamethylenetetramine (HMTA) were dissolved in the dispersion under sonication at 50 °C. 0.175 g of

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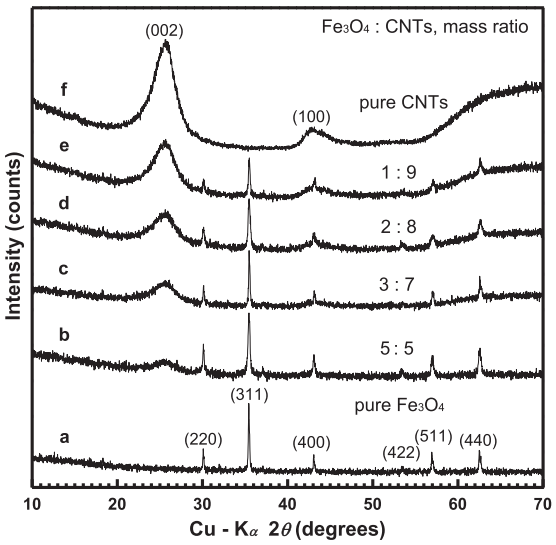

Fig. 1. XRD patterns of pure Fe_3O_4 (a), CNTs (f), and Fe_3O_4-CNTs products with different mass ratio (b-e).

$FeCl_3{\cdot}6H_2O$ (equivalent to 0.050 g Fe_3O_4) was then added under continuous stirring until fully dissolved. The solution was transferred to a 100 mL Teflon-lined autoclave and sealed at 200 °C for 15 h. After that the black precipitate was washed with deionized water and absolute ethanol. Finally the products were dried at 80 °C for 24 h in vacuum. Fe_3O_4 HNSs-CNTs nanocomposites in different mass ratios (2:8, 3:7, 5:5, and pure Fe_3O_4 HNSs) were also synthesized by regulating the dosages of precursors and auxiliary chemicals.

The products were characterized by X-ray diffraction (XRD, PANalytical X'Pert), scanning electron microscopy (SEM, Hitachi SU-70), and transmission electron microscopy (TEM, JEOL JEM 2100F). Then the products were dispersed in silicone oil, and the dielectric heating performance was evaluated using a single mode microwave reactor (CEM, DISCOVER SP) at 50 W, 2.45 GHz for 100 s. The measuring details are shown in Fig. S1 (Electronic Supplementary Material).

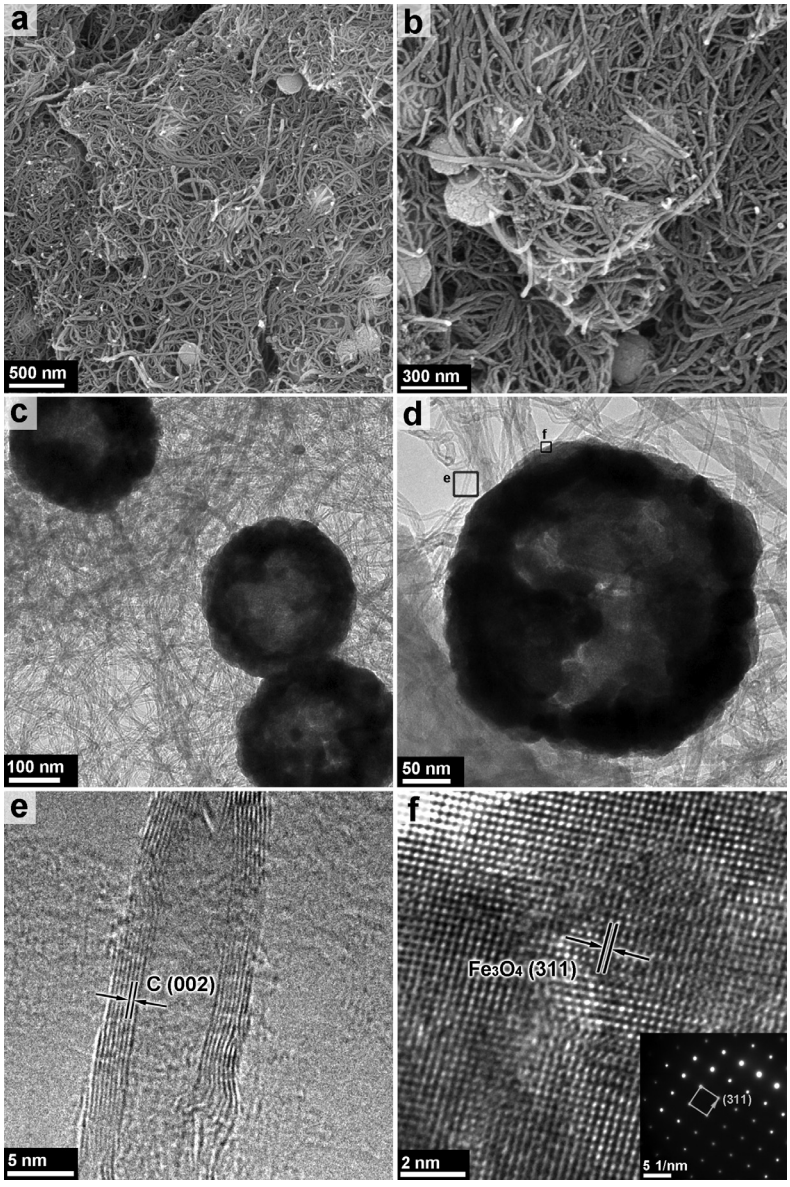

Fig. 2. FESEM (a-b) and TEM (c-f) images of Fe_3O_4 HNSs-CNTs product (mass ratio 1:9).