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Ordered NiO/$NiFe_2O_4$ nanocomposites: Synthesis, exchange bias and magnetic properties

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ABSTRACT

Mesoporous bundled $NiFe_2O_4$ nanowires were synthesized using mesoporous silica SBA-15 as hard template, and then NiO nanoparticles were implanted into $NiFe_2O_4$ nanowires to prepare ordered NiO/$NiFe_2O_4$ nanocomposites. X-ray diffraction, N_2 adsorption-desorption, transmission electron microscopy and energy dispersive spectrometer were used to characterize the microstructure of the as-prepared samples. All results indicated that mesoporous $NiFe_2O_4$ nanowires presented in bundle with the pore-volume percent of about 42% and NiO nanoparticles existed in the mesopores. The magnetic behavior of $NiFe_2O_4$ nanowires and NiO/$NiFe_2O_4$ nanocomposites were investigated with superconducting quantum interference device, and the saturation magnetization decreased with the increasing NiO content, while the coercivity and exchange bias field increased. The exchange bias effect was obviously observed for the NiO/$NiFe_2O_4$ nanocomposites at low temperature and increased with the NiO content. It's concluded that interfaces magnetic interactions and surface energy barrier of NiO nanoparticles greatly affected the magnetic behavior of the NiO/$NiFe_2O_4$ nanocomposites.

1. Introduction

Owing to the synergistic effect and magnetic exchange interactions, magnetic nanocomposites had attracted much attention in the fields of data storage, environmental remediation, targeted therapy, biotechnology, magnetic fluids and so on [1–5]. The magnetic properties of nanocomposites not only depended on the magnetic properties of the (single phase) constituents, but also were affected by the magnetic exchange interactions between the different phase components. These nanocomposites opened up a new opportunity to develop the excellent multifunctional materials, presenting the excellent magnetic properties. Up to now, the magnetic exchange interactions had been found in the Co/CoO, Ni/NiO, Co_3O_4/$CoFe_2O_4$, Co/Cr_2O_3, α-Fe_2O_3/$NdFe_2B_{14}$ nanocomposites for the application in permanent magnets and spin-valve film systems [6–12]. Exchange bias was one of the important exchange interactions from the ferromagnetic (FM)/antiferromagnetic (AFM) interfaces, which increased the coercivity (Hc) and decreased the superparamagnetic critical size of the nanocomposites [13].

Magnetic nanocomposites were among the most interesting systems for both applications and fundamental studies [14,15]. The distribution of the size, shape, defects and phase purity greatly affected the magnetic properties of nanocomposites, which made the investigation of magnetism and exchange interactions of nanocomposites very complex. Such nanocomposites tremendously facilitated the discrimination between finite-size effects, interparticles interactions and surface effects [16]. The synthesis of the monodisperse and uniform nanoparticles had been developed [17–19], which helped us reveal the influence of the surface effects and finite-size effects on the intrinsic magnetic performance. One of the remained challenges was the synthesis of nanocomposites with the well-defined shape, a controlled compositions and tunable interparticles separations. Different methods had been developed for the synthesis of well-controlled nanocomposites [20–22], in which the nanocasting method was easily to obtain ordered nanocomposites [23–29]. Ordered mesoporous templates could effectively control the microstructure and morphology of magnetic materials [30,31]. Kleitz et al. described the synthesis of a series of ordered mixed metal oxides (e.g., $NiFe_2O_4$, $CuFe_2O_4$) via the

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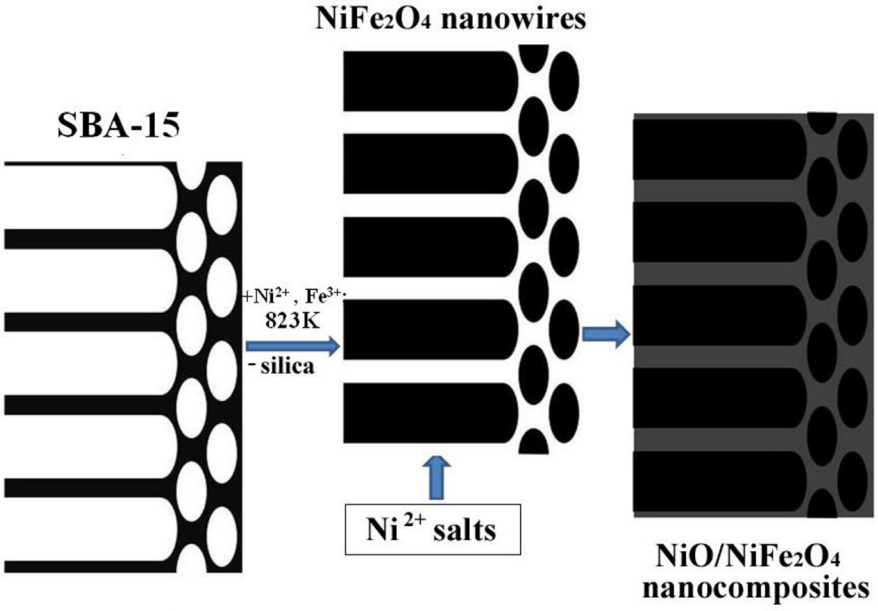

Fig. 1. Schematic representation of the $NiO/NiFe_2O_4$ processing route and nanocomposite structure. On the left, the white was behalf of the mesopores of SBA-15, the black in the middle presented mesoporous bundled $NiFe_2O_4$ nanowires, and the gray between $NiFe_2O_4$ nanowires on the right was behalf of NiO.

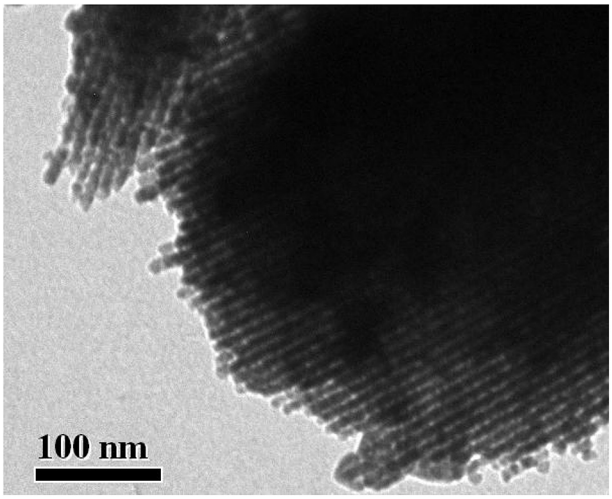

Fig. 2. TEM image of the $NiFe_2O_4$ nanowires.

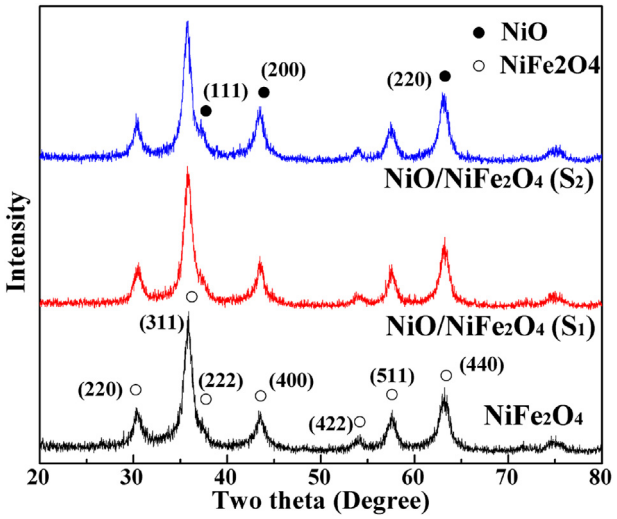

Fig. 3. XRD patterns of $NiFe_2O_4$ nanowires and $NiO/NiFe_2O_4$ nanocomposites (S_1 and S_2).

nanocasting pathway [32]. Harun Tüysüz et al. synthesized ordered $Co_3O_4/CoFe_2O_4$ nanocomposites with the solid–solid reaction using SBA-15 as hard template, and the magnetic exchange bias was observed at low temperature [8].

The controllable microstructure and phase components were very important to investigate the magnetic properties of nanocomposites, which was necessary for the research on the exchange interaction. In this paper, mesoporous magnetic $NiFe_2O_4$ nanowires were synthesized used the ordered mesoporous silica SBA-15 as template by the nanocasting route, and then NiO nanoparticles were introduced into mesoporous $NiFe_2O_4$ nanowires with the impregnation method. The microstructure, components and magnetic properties of the $NiFe_2O_4$ nanowires and $NiO/NiFe_2O_4$ nanocomposites were characterized by X-ray diffraction (XRD), N_2 adsorption-desorption, transmission electron microscope (TEM), energy disperse spectroscopy (EDS) and magnetic measurement. Compared the magnetic properties of $NiFe_2O_4$ nanowires and $NiO/NiFe_2O_4$ nanocomposites, the influence of the interfaces magnetic exchange interactions on the magnetic properties of $NiO/NiFe_2O_4$ nanocomposites could be discussed and deduced in detail.

2. Experimental section

Ordered mesoporous silica SBA-15 was synthesized according to the method reported earlier [33]. 8.315 g of the pluronic P123 (poly (ethylene glycol)-block-poly (propylene glycol)-block-poly (ethylene glycol)) as the soft template were dissolved in 94.235 ml mixture of the distilled water and HCl (1.6 mol). After stirring for 2 h, tetraethyl orthosilicate (11.34 ml) was dropped. The mixture was also stirred for 5 min and aged 24 h at 318 K, and then the solution was treated hydrothermally at 403 K for 24 h. The