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Coexistence of blocked, metamagnetic and canted ferrimagntic phases at high temperature in Co–Nd ferrite nanorods

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ABSTRACT

One-dimensional Co–Nd ferrite nanostructures were prepared by controlled co-precipitation method. Co–Nd ferrite nanorods exhibits different magnetic phases: blocking phase with the corresponding blocking temperature (T_B) of about 350 K, metamagnetic phase with the corresponding Morin transition temperature (T_M) of about 550 K and canted ferrimagntic phase with the corresponding Neel temperature (T_N) of about 800 K. These novel magnetic one-dimensional structures can potentially be used in nanoelectronic devices, magnetic sensors, and flexible magnets.

1. Introduction

Nanostructured materials have received much attention due to their novel properties that differ from those of bulk materials [1,2]. The design, synthesis and characterization of nanophase materials are the subject of intense current research [3,4]. Recently, nanoferrites and their composites have

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gained much attention due to their properties for use in many technological areas such as information storage devices, magnetic contrast agent resonance imaging, quantum tunneling, ferrofluids, sensors, nanoelectronic devices, magnetic sensors, and flexible magnets [5–10]. The spinel nano-ferrites have a lot of interesting properties; they are sensitive to composition, microstructure and heat treatment. It is known that the magnetic behavior of the spinel nano-ferrite is largely governed by the Fe–Fe interaction (the spin coupling of the 3d electrons). By introducing rare earth ions, R, into the spinel lattice, the R–Fe interactions also appear (3d–4f coupling), which can lead to a changes in the magnetic properties. In present scenario, rare earth ions are playing an active role in magnetic oxides and result in various novel properties in perovskites and pyrochlores [11,12]. Recently, several works have been devoted to synthesis and characterization of nanostructures ferrites spinel [13–18]. In spite of enormous works on substitution in spinel nano-ferrite, less attention has been paid to the substitution of rare earth ions in spinel nano-ferrite. More experimental investigation of R substitution may provide fundamental theoretical understanding of coupling effect between 3*d*–4*f* spins in spinel nano-ferrite.

We herein report the magnetic properties of Co–Nd spinel ferrite nanorods. The nanorods with a mean size (Diameter (6 nm) and Length (40 nm)) are prepared with a co-precipitation method. Co–Nd ferrite nanorods display complex magnetic properties that dramatically change at three significant temperatures.

2. Experimental section

2.1. Preparation

The chemical reagents for this experiment are $FeCl_2·4H_2O$, $NdCl_3$, $FeCl_3·6H_2O$, $CoCl_2·6H_2O$ and NaOH. For sample preparation, raw materials were first of all made to weight according to prescribed compound ratios, and then mixed solutions were prepared with pure water and mixed homogeneously and refluxed under air atmosphere to yield a uniform mixture of precursor at 80 °C for 30 min. Secondly, while agitating well, NaOH aqueous solution (6 mol/l) was added to this mixed solution (pH of the medium 11). Then, the precipitation was aged at 120 °C for 2 h. The precipitates were washed several times with water and ethanol to remove the water-soluble impurities and free reactants and then dried at 80 °C overnight. Heating treatments of the synthesized powder was conducted at 400 °C for 2 h. The precursor was tested by X-ray diffraction (XRD) with a (D8 ADVANCE BRUKER AXS) and the magnetic characterization was done by Magnetic Properties Measurement System (MPMS SQUID VSM Quantum design).

2.2. Structure and magnetic characterization

The crystal structure of $Nd_{0.5}Co_{0.5}Fe_2O_4$ nano-powders sintered at a temperature of 400 °C is determined by X-ray diffraction, given in Fig. 1. Positions and relative intensities of all observed peaks indicate that the crystalline structure of samples favors the formation of only cubic spinel phase. TEM (transmission electron microscopy) enables more insight in visualizing the nano-scale organization of these materials. Indeed, $Nd_{0.5}Co_{0.5}Fe_2O_4$ nano-powders feature typical nanorods morphology with a typical growth in one-dimension with a mean size (Diameter (6 nm) and Length (40 nm)) (see Fig. 1). The analysis of the magnetization as a function of temperature showed the presence of three magnetic transitions giving three different magnetic behaviors before reaching the paramagnetic state. The first is a blocking phase. As shown in Fig. 2, for low temperature measurement the Field Cooled (FC) and Zero Field Cooled (ZFC) magnetization curves split significantly; the FC magnetization rises slowly, while the ZFC curve rises significantly. The split between the FC and ZFC curves reflects the blocking of nanoparticles magnetization (nanoparticles still in a magnetic blocked sate). The measured ZFC curve is broad indicating a large distribution of particles sizes, without single localized maximum characteristic of narrow size distribution of isolated particles. This behavior marks the presence of super-paramagnetic particles. Therefore the branching of the two curves occurs at high temperature inducing a T_B = 320 K. An abrupt increase of the magnetization above T_B was observed, which has not a