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Effect of particle size on structural, magnetic and dielectric properties of manganese substituted nickel ferrite nanoparticles

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ABSTRACT

Mn substituted $NiFe_2O_4$ ferrite nanoparticles (Mn–$NiFe_2O_4$) were synthesized by the auto-combustion method. Their actions were carried out at different fuel ratios (50%, 75% and 100%). The nanoparticles have been investigated by X-ray powder diffraction, scanning electron microscopy and transmission electron microscopy. The average crystallite size of the synthesized and annealed samples was between 25 and 75 nm, which were found to be dependent on both fuel ratio and annealing temperatures. However, lattice parameters, interplanar spacing and grain size were controlled by varying the fuel ratio. Magnetic characterizations of the nanoparticles were carried out using a vibrating sample magnetometer at room temperature. The saturation magnetization was computed and found to lie between 6 emu/g and 57 emu/g depending on the particle size of the studied sample. The coercivity was found to exhibit non-monotonic behavior with the particle size. Such behavior can be accounted for by the combination between surface anisotropy and thermal energies. The value of dielectric constant and dielectric loss was found to exhibit almost linear dependence on the particle size.

1. Introduction

The Mn–$NiFe_2O_4$ nanoparticle has possessed excellent magnetic and dielectric property. These ferrite nanoparticles are generally used in magnetic fluids, magnetic recording media, microwave devices, magnetic resonance imaging, magnetic carriers for drug targeting, catalysis and sensors [1–3]. The structural and magnetic properties of spinel ferrite nanoparticles are strongly influenced by their composition and microstructures, which are sensitive to the preparation methods. There are several methods for synthesizing the nanosized magnetic spinel ferrite particles, such as co-precipitation [4], sol–gel [5], solid state reaction method [6], conventional double-sintering [7], microwave-induced combustion [8], microwave refluxing method [9], combustion method [10–12], microwave hydrothermal method [13], mechanochemical process [14], high-energy ball milling [15] and hydrothermal method [16]. Among these methods, here we used simple cost effect and low temperature synthesis method with some noticeable change. This paper presents the structural, morphological, magnetic and dielectric properties of manganese substituted $NiFe_2O_4$ nanoparticles prepared by the auto-combustion method. In this method, three different ratios of fuel (urea) such as 50%, 75% and 100% have been used to analyze the properties of the ferrites with help of reaction time.

2. Experimental details

2.1. The auto-combustion method

Manganese substituted nickel ferrite nanoparticles with the chemical formula $Mn_{0.4}Ni_{0.6}Fe_2O_4$ have been prepared by an auto-combustion technique. The analytical grade manganese nitrate [$Mn(NO_3)_2 \cdot 6H_2O$], nickel nitrate [$Ni(NO_3)_2 \cdot 6H_2O$], ferric nitrate [$Fe(NO_3)_3 \cdot 9H_2O$], and urea [$CO(NH_2)_2$] were used as raw materials. The combustion process was changed by adding the different percentages of urea such as 50%, 75% and 100%. Subsequently, 0.4 mol of manganese nitrate, 0.6 mol of nickel nitrate, 2 mol of ferric nitrate and urea were dissolved in deionized water to form mixed solution. Then the mixture was heated up to 160 °C to dehydrate until self-ignition takes place. The process of ignition was occurred in air at room temperature and burnt under self-propagating combustion, which exhausted a large amount of gases and

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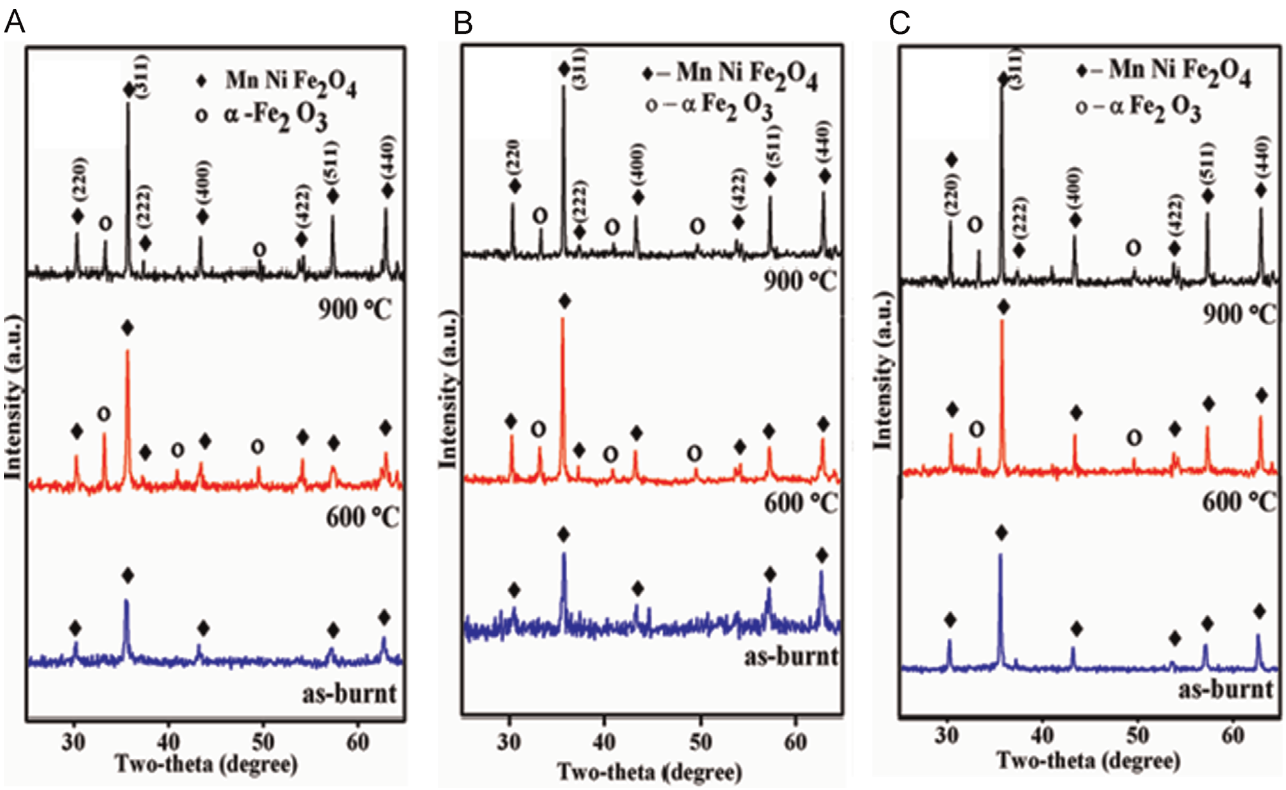

Fig. 1. XRD pattern of manganese substituted $NiFe_2O_4$ nanoparticles prepared by the auto-combustion method: A – 50% fuel ratio, B – 75% fuel ratio and C – 100% fuel ratio.

Table 1
Particle size, lattice constant, magnetic and dielectric values of Mn substituted $NiFe_2O_4$ nanoparticles.

Parameters of Mn–$NiFe_2O_4$	Mn–$NiFe_2O_4$ (fuel ratio 50%)			Mn–$NiFe_2O_4$ (fuel ratio 75%)			Mn–$NiFe_2O_4$ (fuel ratio 100%)		
	As-burnt	600 °C	900 °C	As-burnt	600 °C	900 °C	As-burnt	600 °C	900 °C
Particle size, t (nm)	25	52	65	27	56	67	34	58	75
Lattice constant, a (Å)	8.44	8.45	8.47	8.44	8.46	8.47	8.45	8.46	8.47
Saturation magnetization, M_s (emu/g)	8.33	6.79	26.36	30.25	26.4	32.45	37.7	29.59	57.37
Coercivity, H_c (G)	146	150	87	101.92	151.6	75.4	93.2	127.66	97.99
Dielectric constant, $\acute{\varepsilon}$	586	437	287	440	324	234	290	220	189
Dielectric loss, D	4.1	3.45	2.29	3.73	2.85	1.88	2.98	2.24	1.62

producing the ferrite powder. Throughout the combustion process no pH adjustment was made. The influence of heat treatment was also done for the samples for which a portion of the as-burnt ferrite powders was sintered at 600 °C and 900 °C for 5 h using muffle furnace. Similar process is repeated for all three combustion fuel ratios.

2.2. Equipment used for characterization

The Mn–Ni ferrite powders were subjected to XRD analyses with Rigaku X-ray diffraction unit (Model ULTIMA III) to obtain the structural properties. A scanning electron microscope (SEM with EDX) was used to examine the morphology, using a JEOL 5600LV microscope at an accelerating voltage of 10 kV. High resolution transmission electron microscopy (HRTEM) and selected-area electron diffraction (SAED) were recorded for all the samples on a Technai G20-stwin using an accelerating voltage of 200 kV. The dielectric properties of the samples were measured by a Digital LCR meter (Model TH2816A) in the frequency range from 100 kHz to 5 MHz.

3. Results and discussion

3.1. X-ray diffraction analysis

Fig. 1 depicts the XRD pattern to determine the phase compositions of the prepared and annealed samples of Mn–Ni ferrite nanoparticles. The reflection peaks correspond to the characteristic interplanar spacing between (220), (311), (222), (400), (422), (511) and (440) planes of the spinel ferrite with a cubic symmetry, demonstrating the formation of Mn–Ni ferrites as per JCPDS data (22-1012). Fig. 1 represents of crystalline behavior of the samples