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Synthesis and characterization of nickel zinc ferrite nanoparticles

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Abstract

In this research nickel zinc ferrite nanoparticles with composition of $Ni_{1-x}Zn_xFe_2O_4$ (where x=0, 0.3, 0.7, 1) were synthesized by a sol-gel method at 600 °C for 5 hours. The structure of nanoparticles was studied using X-ray diffraction pattern. The lattice parameter of ferrite nanoparticles was calculated and indicates lattice constant of nanoparticles depend on zinc concentration. The crystallite size of nickel zinc nanoparticles was calculated by Debye–Scherrer equation and the crystallite sizes of nanoparticles decreased by increasing in x contents. Morphology of nanoparticles was observed and investigated using the scanning electron microscopy. The grain size of nickel zinc ferrite nanoparticles were in suitable agreement with the crystalline size calculated by X-ray diffraction results. Magnetic properties of nanoparticles were examined with vibration sample magnetometer. Hysteresis loops of nanoparticles reveal the super-paramagnetic behavior.

1. Introduction

Nickel zinc ferrite nanoparticles are the technological important ferrites. Ni-Zn ferrites because high electrical resistivity, high magnetic permeability, high mechanical strength, low dielectric loss, low coercivities and good chemical stability have many application in electromagnetic such as inductors, data storage devices, actuators, magnetic sensors, targeted drug delivery, medical diagnosis and electromagnetic wave absorbers [1-5].

Some properties of nanoparticles depend on choosing synthesis method. The chemical methods like hydrothermal, citrate precursor, co-precipitation and sol-gel process. The sol-gel method because high purity, small and homogeneous nanoparticles size, energy saving, minimal evaporation loss, low cost is more advantage method [6-8].

Nickel zinc ferrite has a spinal structure that nickel ferrites and zinc ferrites have inverse spinel and normal spinel structure respectively [9].

In this work investigate the effect of doping nonmagnetic zinc ions to nickel ferrite on structural and magnetic properties of $Ni_{1-x}Zn_xFe_2O_4$ nanoparticles.

2. Experimental procedure

The nanoparticles composition of $Ni_{1-x}Zn_xFe_2O_4$ (where x=0, 0.3, 0.7, 1) chemical were synthesized by the sol-gel method. The chemical precursors used in reaction were iron (III) nitrate nonahydrate ($(Fe(NO_3)_3).9H_2O$), nickel nitrate hexahydrate ($Ni(NO_3)_2.6H_2O$), zinc nitrate hexahydrate ($Zn(NO_3)_2.6H_2O$), citric acid ($C_6H_8O_7$) and distilled water (all materials from Merck Company were used without further purification). In first the metal nitrates and citric acid dissolved in distilled water in required molar ratios. The obtained solution were heated using a hot plate on 75°C with stirring until forming the gel. Then the temperature was increased to 250°C until preparation a dry gel. Afterwards, the nickel zinc ferrite powder heated in 600°C for 5h.

Structure of nanoparticles was studied using X-ray diffraction (XRD) with CuKα (λ=1.54 Å) radiation. The shape and size of nanoparticles were investigated by scanning electron microscope (SEM) images. And the magnetic measurements of nickel zinc ferrite nanoparticles were prepared at room temperature using a vibrating sample magnetometer (VSM).

3. Results and discussion

XRD analyses were performed to determine the crystalline structure and phase formation of nickel zinc ferrite nanoparticles. The XRD patterns for $Ni_{1-x}Zn_xFe_2O_4$ (x=0, 0.3, 0.7, 1) is shown in figure 1a-d respectively. X-ray diffraction indicates a cubic spinal structure for the all range of zinc concentration. The XRD patterns confirm with increasing in Zn (x) contents the lattice parameter increased. The increasing lattice constant of nanoparticles dependence to radius of Zn^{2+} and Ni^{2+} ions in to crystal structure. The radius of Zn^{2+} (0.82 Å) is bigger than Ni^{2+} (0.78 Å), therefore by replacement zinc ions with nickel ions the lattice constant increased. The lattice parameter of nickel zinc ferrite nanoparticles calculated 8.341, 8.354, 8.378 and 8.415 Å for x=0, 0.3, 0.7, 1 respectively.

The nanoparticles crystallite size was calculated from X-ray line broadening using (311) peak and Debye–Scherrer equation [10]:

$$D=0.9\lambda/\beta \cos\theta$$

where λ is the X-ray wavelength (CuKα radiation equals to 1.54Å), θ is the Bragg diffraction angle, and β is the FWHM of the XRD peak appearing at the diffraction angle θ. The crystallite sizes calculated are about 48, 42, 39 and 36 nm for the samples with x=0, 0.3, 0.7, 1 respectively. The results are in a good agreement with other research groups [9, 11, 12].

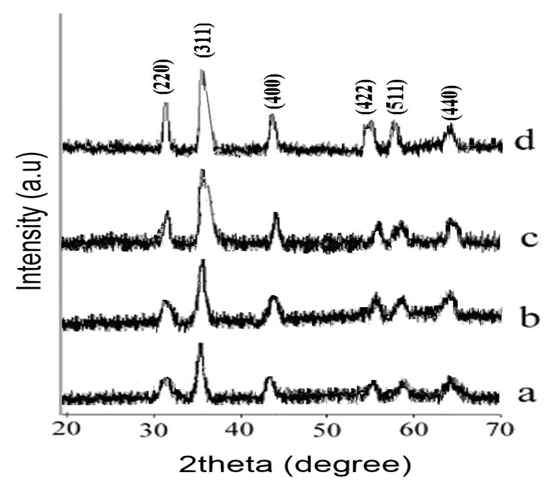

Fig. 1. XRD patterns of $Ni_{1-x}Zn_xFe_2O_4$ nanoparticles for a) x=0, b) x=0.3, c) x=0.7 and d) x=1.

The SEM images of $Ni_{1-x}Zn_xFe_2O_4$ nanoparticles for x=0, 0.3, 0.7, 1 are indicated in figure 2a-d respectively.

The size of nanoparticles were approximately the same but by increasing the zinc content a little decrease in particle size was observed that is in appropriate agreement to XRD results.

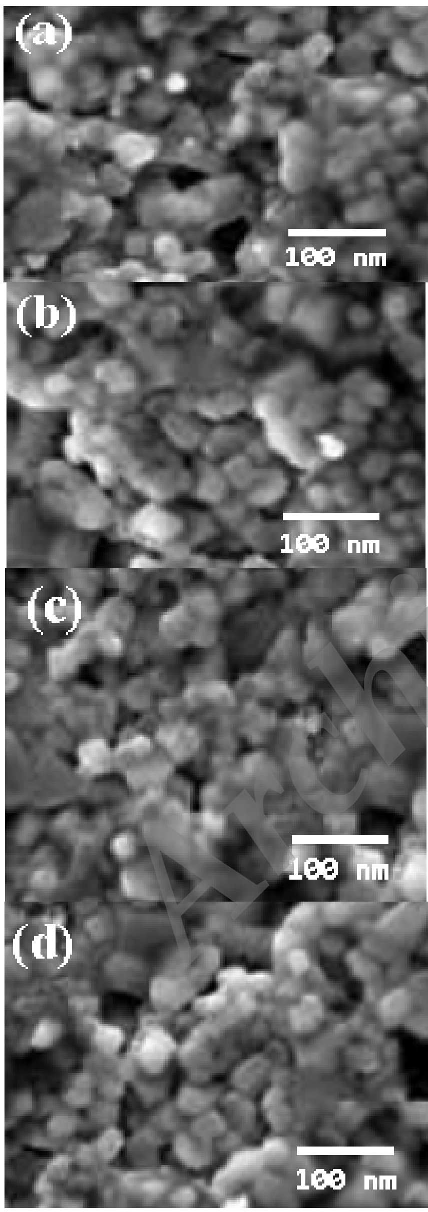

Fig. 2. SEM images of $Ni_{1-x}Zn_xFe_2O_4$ nanoparticles for a) x=0, b) x=0.3, c) x=0.7 and d) x=1.

Field dependence of magnetization of nickel zinc ferrite nanoparticles were performed at room temperature using a vibrating sample magnetometer instrument.

The hysteresis loop of nickel zinc ferrite nanoparticles for different zinc concentrations are shown in figure 3. The hysteresis loops for all samples indicate no hysteresis and it is attributed to super-paramagnetic behaviour.

The saturation magnetization of $Ni_{1-x}Zn_xFe_2O_4$ for x= 0, 0.3, 0.7 and 1 are 75.3, 86.4, 61.5 and 44.2 emu/cm^3 respectively. The hysteresis loops indicate increasing at ratio x=0 and 0.3 then decreasing at ratio x= 0.7 and 1. These results have a suitable agreement with other research group outcomes [9, 11]. The zinc contents dependence saturation magnetization is illustrated in figure 4.

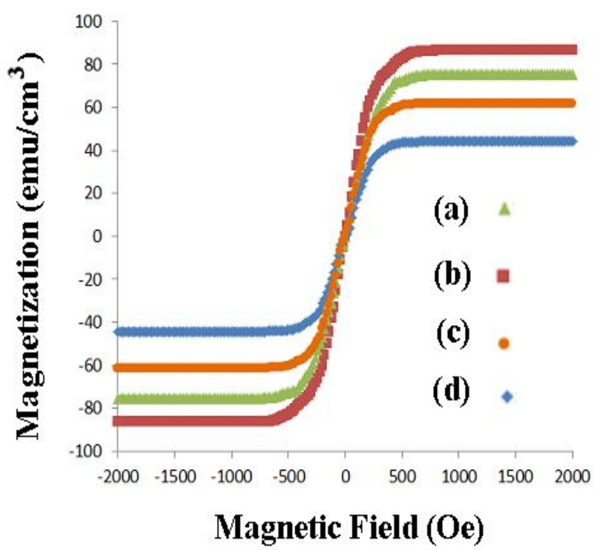

Fig. 3. hysteresis loops of $Ni_{1-x}Zn_xFe_2O_4$ nanoparticles for a) x=0, b) x=0.3, c) x=0.7 and d) x=1.

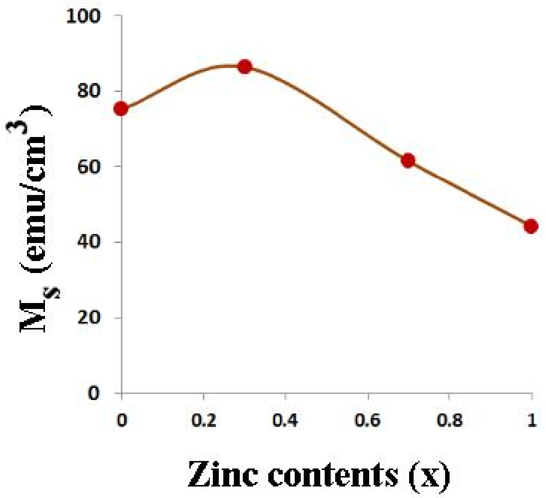

Fig. 4. Zinc contents dependence saturation magnetization of $Ni_{1-x}Zn_xFe_2O_4$ nanoparticles.

4. Conclusion

Nickel zinc ferrite ($Ni_{1-x}Zn_xFe_2O_4$) nanoparticles were synthesized by sol-gel method in different zinc concentrations where x=0, 0.3, 0.7, 1.

XRD patterns indicate a cubic spinel structure that with increasing in Zn contents the lattice constants increased and crystalline size decreased.

The morphological investigation indicates by increasing zinc concentration the grain sizes decreased.

Magnetic measurements reveal the super-paramagnetic behavior for nickel zinc ferrite nanoparticles and by increasing zinc concentration the saturate magnetization firstly increased and after ratio of 0.3 decreased.

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