

Q-Factor measurement of $\text{Ni}_{0.7}\text{Zn}_{0.3}\text{Fe}_2\text{O}_4$ nanoparticles up to 3 MHz frequencies

G. R. AMIRI*, M. H. YOUSEFI^a, S. FATAHIAN

Falavarjan Branch, Islamic Azad University, Isfahan, Iran

^aDepartment of sciences, Nano-center, Malek-ashtar University of Technology, Isfahan, Iran

$\text{Ni}_{0.7}\text{Zn}_{0.3}\text{Fe}_2\text{O}_4$ nanoparticles (9-42 nm) were synthesized by low-temperature solid-state reaction (LTSSR) method. Transmission electron microscopy (TEM) and X-ray diffractometer (XRD) were used to analyze the structural properties. It was found that the particle size and magnetic properties of the prepared ferrite sample showed strong dependence on the annealing temperature. The coercivity initially increased and then decreased with increasing the annealing temperature whereas the particle size and saturation magnetization continuously increased. Q-Factor (quality factor) of $\text{Ni}_{0.7}\text{Zn}_{0.3}\text{Fe}_2\text{O}_4$ was measured by LCR-Meter which was constant and maximum in the broad band frequency from 0.5 to 3 MHz.

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1. Introduction

Ferrites are the magnetic materials which consist of a mixed oxide of iron and other elements that are prepared to obtain crystalline structure. The crystalline structure is made by heating the ferrite material at an ultra high temperature for a proper time and protocol. The general composition of ferrites is xxFe_2O_4 where xx represents several metals. One of the most famous metal combinations is nickel and zinc (NiZn) which can be easily magnetized. Magnetic nanoparticles have some important industrial and medical applications [1, 2].

For instance, microwave absorbers are in use since long, both in civil and military application, on account of their ability to eliminate electromagnetic wave pollution and to reduce microwave signatures. Recently, the demand for microwave absorbers has increased in the frequency range of 1-20 GHz, because of their two-fold use: electromagnetic interference shielding and countermeasure to microwave detection. Spinel ferrites based on Ni-Zn have been used as high-frequency ferrites for transformers core, rod antennas, radio frequency and more recently as microwave absorbing materials [3-7]. Basic properties of those nanoparticles were also compared with that of bulk samples [8]. In this work we used the low-temperature solid-state reaction (LTSSR) method to synthesize nanoparticles [3, 4]. The nanocrystallite of these materials was characterized by structural and magnetic methods. In this essay, the quality factor (Q-factor) was also determined.

The Q-factor is an important characteristic for inductors. The energy dissipation in inductors depends on the Q-factor of inductors. As the Q-factor of inductors increases, the energy dissipation in inductors decreases.

The Q value of an inductor is a measure of the relative losses in an inductor. The Q is also known as the “quality

factor” and is technically defined as the ratio of inductive reactance to effective resistance.

2. Experimental details

2.1. Synthesize of ferrite powders

The Ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$), nickel chloride ($\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$), zinc chloride (ZnCl_2) and sodium hydroxide (NaOH), provided with high purities from Merck. Powders of ZnCl_2 , $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$, $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ and NaOH were mixed in their stoichiometric ratios (1:1:2:8). Then the mixture was milled at room temperature. Finally, the nanoparticles were washed with distilled water several times [3, 4].

The five specimen of the Ni-Zn ferrites were synthesized as follow: $\text{Ni}_{0.7}\text{Zn}_{0.3}\text{Fe}_2\text{O}_4$ annealed at 30 °C (Ni30), $\text{Ni}_{0.7}\text{Zn}_{0.3}\text{Fe}_2\text{O}_4$ annealed at 500 °C for 3h (Ni500), $\text{Ni}_{0.7}\text{Zn}_{0.3}\text{Fe}_2\text{O}_4$ annealed at 800 °C for 3h (Ni800), $\text{Ni}_{0.7}\text{Zn}_{0.3}\text{Fe}_2\text{O}_4$ annealed at 1000 °C for 3h (Ni1000) and $\text{Ni}_{0.7}\text{Zn}_{0.3}\text{Fe}_2\text{O}_4$ annealed at 1200 °C for 3h (Ni1200).

2.2 Preparation of ferrite core

In order to explore the quality factor (Q factor), $\text{Ni}_{0.7}\text{Zn}_{0.3}\text{Fe}_2\text{O}_4$ nanoparticles were mixed with glycerin by the weight ration of 10:1. Then the acetone was added to the mixture for better mixing. The obtained mixture was heated up to 100 °C in order to evaporation of acetone. After that the mixture was put to a mould and pressed under 11 MPa pressure (1.5 MPa in return for every cm^2 of mould). The obtained mixture was heated up to 350 °C in order to evaporation of glycerin. Then the final mixture was cured under the following protocol. First heated 8 hours up to 1100 °C and keep at this temperature for 3

hours, then cooled slowly for 6 hours up to room temperature all at the atmosphere control condition.

2.3. Measurement of properties and Q factor

X-ray Diffraction (XRD) patterns were recorded on a Bruker D8 ADVANCE X-ray diffractometer with Cu-K α radiation.

The room temperature magnetization measurements up to a maximum field of 10 KOe were carried out using alternating gradient field magnetometers (AGFM) (Company Meghnatis Daghigh Kavir Co.). Transmission electron microscope (TEM) was used for size and size distribution. Inductance, capacity and resistance -Meters (LCR-Meters) were used for determining the Q-factor.

The Q-Factor is a measure of the frequency selectivity of a resonant or ant resonant circuit, and it is defined as:

$$Q = 2\pi \frac{\text{Maximum Energy Stored}}{\text{Energy Dissipated per Cycle}} \quad (1)$$

The Q value of an inductor is a measure of the relative losses in an inductor. The Q is also known as the “quality factor” and is technically defined as the ratio of inductive reactance to effective resistance. and is represented by:

$$Q = \frac{X_L}{R} = \frac{\omega L}{R} = \frac{2\pi f L}{R} \quad (2)$$

Since X_L and R are functions of frequency, the test frequency must be given when specifying Q. X_L typically increases with frequency at a faster rate than R at lower

frequencies, and vice versa at higher frequencies. This results is a bell-shaped curve for Q versus frequency. R is mainly comprised of the DC resistance of the wire, the core losses and skin effect of the wire. Based on the above formula, it can be shown that the Q is zero at the self-resonant frequency since the inductance is zero at this point.

By using a ferrite core, the inductance is dramatically increased for the same amount of other metals, multiplying up the Q. A grade of core material is selected for best results for the frequency band. At VHF or higher frequencies an air core is likely to be used.

3. Results and discussion

3.1. Microstructure

XRD patterns for Ni_{0.7}Zn_{0.3}Fe₂O₄ (annealed at 30-1200 °C for 3h) are shown in Fig. 1. The average particle size for all Ni_{0.7}Zn_{0.3}Fe₂O₄ powders was calculated by Debye-Scherrer formula. It was estimated within 10 to 40 nm which is shown by detail in Table 1. The crystal phase of Ni_{0.7}Zn_{0.3}Fe₂O₄ was obtained and indicated plane structure at 1000 °C. The crystal phase of Ni_{0.7}Zn_{0.3}Fe₂O₄ was destroyed at 1200°C.

Fig. 2 shows the TEM pattern of the Ni_{0.7}Zn_{0.3}Fe₂O₄ ferrite. The average particle size which estimated from the TEM pattern was found between 11 to 42 nm. In conclusion the measurements of XRD were confirmed by the results of TEM photographs.

Table 1. Magnetic properties and crystal size of the Ni_{0.7}Zn_{0.3}Fe₂O₄ ferrite.

specimen	M(emu/g)*	Mr(emu/g)	Hc(Oe)**	FWHM (Peak 311) (degree)	D (nm)
Ni30 (without heat-treatment)	3.6	0.04	7	0.71	10
Ni500 (annealed at 500 °c for 3h)	22	1.5	29	0.6	12
Ni800 (annealed at 800 °c for 3h)	35	5.4	77	0.5	15
Ni1000 (annealed at 1000 °c for 3h)	65	5.3	35	0.24	30
Ni1200 (annealed at 1200 °c for 3h)	32	2.2	22	0.2	40

*emu= electromagnetic unit, **Oe: Oersted

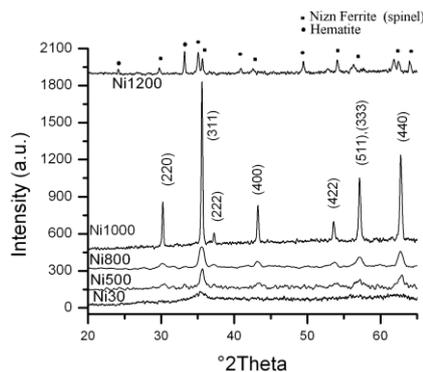


Fig. 1. X-ray diffraction pattern of the as-prepared nanocrystalline Ni_{0.7}Zn_{0.3}Fe₂O₄ annealed at different temperature.

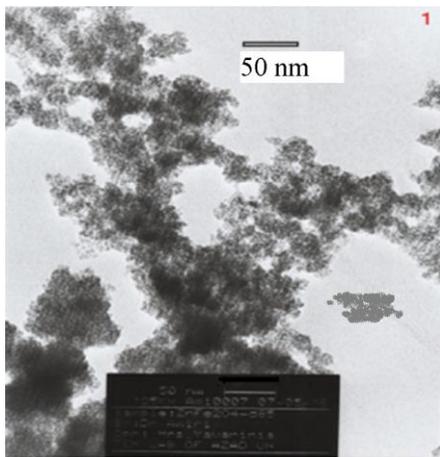


Fig. 2. Transmission Electron Micrograph of $Ni_{0.7}Zn_{0.3}Fe_2O_4$ calcined at 30 °C.

Fig. 3 and 4 show the results of $Ni_{0.7}Zn_{0.3}Fe_2O_4$ AGFM measurements for different temperatures from 30 to 1200 °C. The variations of relative magnetization were traced and it was found that the optimum temperature is 1000 °C. In this temperature the saturation may happen. Also magnetic parameters were changed as recorded in Table 1. Fig. 3 and 4 show the variation of saturation magnetization (M_s) and coercivity (H_c) with the annealing temperature. The Gaussian fit to the data shows that coercivity increases at annealing temperature higher than 800 °C. The changes in magnetic properties of $Ni_{0.7}Zn_{0.3}Fe_2O_4$ ferrites can be attributed to the modification of the particle size dependent on the annealing temperature [9]. The decrease in saturation magnetization is due to decrease in particle size and surface spin effects of small particles. The formations of surface layer in those magnetic moments, do not contribute to the magnetization of the applied field [10]. The coercivity for single domain particles decreases with particle size and becomes very small for the presence of a considerable volume fraction of superparamagnetic particles [11]. As can be seen, the samples with nanocrystallite sizes less than 10 nm have superparamagnetic behavior at room temperature.

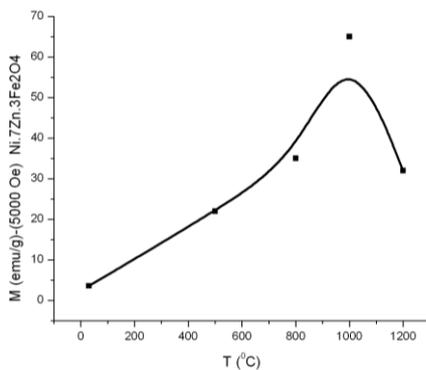


Fig. 3. Variation of saturation magnetization of $Ni_{0.7}Zn_{0.3}Fe_2O_4$ ferrites as a function of annealing temperature.

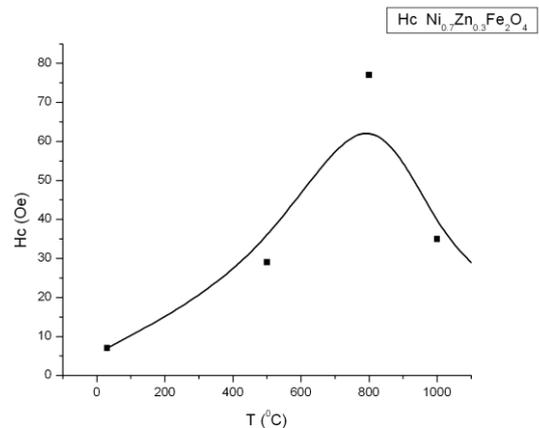


Fig. 4. Variation of coercivity (H_c) of $Ni_{0.7}Zn_{0.3}Fe_2O_4$ ferrites as a function of annealing temperature.

3.2 Q-Factor

Fig. 5 shows Q-Factor (quality factor) of $Ni_{0.7}Zn_{0.3}Fe_2O_4$ which was measured by LCR-Meter. The values of Q-Factor were normalized by dividing to its maximum value. It can be seen that the Q-Factor is constant from 0.5 MHz to 3 MHz and it means that dissipated energy is low in this bandwidth of frequency and the frequency variation from 0.5 MHz to 3 MHz obtained a good quality factor which gives a broad band frequency.

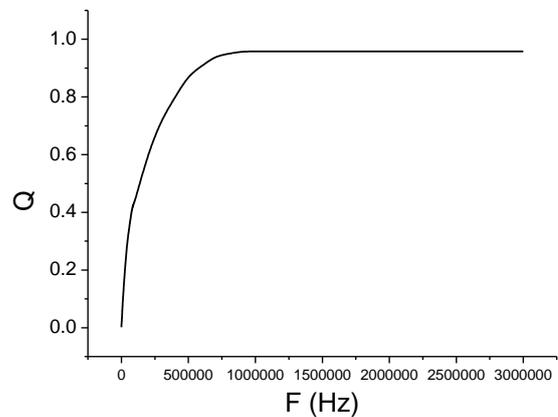


Fig. 5. Quality Factor (Q -Points) by LCR-Meters for $Ni_{0.7}Zn_{0.3}Fe_2O_4$.

4. Conclusions

X-ray diffraction analysis confirms the formation of a spinel phase, and particle size of the ferrite samples increase with the annealing temperature. The magnetic measurements results represented that the coercivity initially increases and then decreases with increasing the annealing temperature whereas saturation magnetization continuously increases. The Q-Factor was constant from 0.5 MHz to 3 MHz and it means that dissipated energy is low in this bandwidth of frequency. In conclusion, $Ni_{0.7}$

$\text{Zn}_{0.3}\text{Fe}_2\text{O}_4$ ferrite may be a promising potential for use as a material which can work at high frequencies up to 3 MHz.

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*Corresponding author: amiri@iaufala.ac.ir