ELASTIC PROPERTIES OF Ni-Cu-Zn FERRITE NANOPOWDERS

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Cu-substituted Ni-Zn ferrites were synthesized by thermal method. X-ray phase and IR spectra of the $Ni_{0.4}Cu_xZn_{0.6-x}Fe_2O_4$ (x=0-0.6) ferrites were studied and it was determined that all obtained samples are spinel ferrites with a single-phase cubic structure. The coefficients of elasticity were calculated using the parameters obtained from the analyzes and the dependence of these coefficients on the concentration of Cu ion was determined.

Keywords: ferrites, thermal method, X-ray phase, IR spectroscopy, sublattice, elastic properties.
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INTRODUCTION

In recent years, there has been an increased interest in the study of nanoferrites with a spinel structure, which have a wide range of practical applications due to their unique physical properties. The physical properties such as mechanical hardness, chemical stability, high saturation magnetization, massive magnetic resistance, semiconductor-dielectric transition, high dielectric permeability have expanded their applications in spintronic, memory devices, computer components, magnetic receivers, magnetic recording devices, gas detectors, transformer casings, in biomedicine and other fields. Ferrite spinels with the general formula $(A^{2+})[B^{3+}]O_4^{2-}$ have a surface-centered cubic structure [1,2]. There are three types of them: normal, transformed and mixed. A^{2+} and B^{3+} are divalent and trivalent metal cations located in tetrahedral (A) and octahedral (B) sublattices. Divalent cations can occupy both sublattices. When this cation resides in the tetrahedral sublattice, normal spinel is formed, and when it resides in both sublattices, inverted spinel is formed. Recently, the most relevant issue of practical application is the management of physical, chemical and electromagnetic properties of the synthesized material [3,4]. As a rule, the physical, chemical, structural and electromagnetic properties of the material are strongly dependent on the replacement of the composition, synthesis process. In the literature analysis [1-7], the absence of a detailed description of the changes in Ni-Zn ferrite materials shows that the study of these materials is still relevant.

It is also important to study the mechanical properties of ferrite materials. Because determining the mechanical properties of ferrites, for example, elasticity coefficients and Debye temperature, allows determining the nature of bonding forces. Usually, the method of transmission of ultrasonic pulses is used to determine the coefficients of elasticity [8, 9, 16]. However, this method has a number of shortcomings. First of all, a large amount of material is required. It is known that for the investigation of each material's structure we use X-ray and IR spectral analysis. We can determine the elasticity properties of our material by the using obtained results,. There are two methods for determining the elastic properties of crystals: determination of elastic properties through the coefficient of elastic stiffness (C_{ij}) and the coefficient of elastic strain (S_{ij}). A total of thirty-six elasticity coefficients are available. For crystals with a homogeneous cubic structure, it is sufficient to determine three elasticity constants (C_{11}, C_{12}, C_{44}).

In this article, the elasticity properties of $Ni_{0.4}Cu_xZn_{0.6-x}Fe_2O_4$ (x=0-0.6) nanoferrite powders synthesized by the thermal method were studied by the Waldron method. Thus, the elasticity coefficients were calculated based on the parameters obtained from the X-ray phase and IR spectral analyses, and the dependence of the obtained parameters on the Cu ion concentration was presented.

1. MATERIALS AND METHODS

The properties of ferrite materials depend on its chemical composition and synthesis method. Information about synthesis technology is published in [8,9,11] works. Oxide-based $Ni_{0.4}Cu_xZn_{0.6-x}Fe_2O_4$ (x=0-0.6) nanoferrite powders with different concentrations were synthesized by thermal method. NiO, CuO, ZnO and Fe_2O_3 oxides with a purity of 99% were used as raw materials. The quality of the synthesized ferrite powders was evaluated by XRDD8 ADVANCE (Bruker, Germany) X-ray diffractometer. The dimensions of the crystal were calculated based on Scherrer's formula [12]. IR spectra were obtained using a Fourier Vertex70 spectrometer (Bruker, Germany).

2. DISCUSSION OF OBTAINED RESULTS.

2.1 X-ray phase analysis

X-ray diffraction spectra of $Ni_{0.4}Cu_xZn_{0.6-x}Fe_2O_4$ (x=0-0.6) ferrite nanopowders are given in [12-15]. From the received spectra, the (111), (220), (311), (222), (400), (422), (511) and (440) maxima characteristic of the cubic spinel structure were observed in each of the studied ferrite samples. This

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shows that $Ni_{0.4}Cu_xZn_{0.6-x}Fe_2O_4$ (x=0-0.6) nanoferrites are ferrites with $Fd3mO^7_h$ spatial symmetry structure. The strongest reflection maximum was recorded on the (311) plane [14]. The lattice parameter, lattice volume and X-ray density porosity parameter of the samples were calculated in the diffraction spectra. The obtained results are presented in table 1. As a result of substitution in Ni – Zn ferrite, we can explain the reduction of the lattice parameter by the fact that the ionic radius of the substituted Cu^{2+}(0.72 Å) ion is smaller than the ionic radius of the Zn^{2+}(0.82 Å) ion [1]. We can see that other parameters also decrease depending on the concentration of Cu^{2+} ion.

Table 1

Lattice parameter (a), lattice volume (V), volume density (ρ_{bulk}), X-ray density ($\rho_{X\text{-}ray}$), porosity P (%), jump of $Ni_{0.4}Cu_xZn_{0.6-x}Fe_2O_4$ (x=0-0.6) ferrites with different concentrations length (L_A, L_B).

X	a (Å)	V(Å)	ρ_{bulk} (g/cm^3)	$\rho_{X\text{-}ray}$ (g/cm^3)	P (%)	L_A (Å)	L_B (Å)
0.0	8.396	591.860	2.55	5.35	52.34	3.635	2.964
0.24	8.384	589.323	2.57	5.37	52.14	3.630	2.960
0.3	8.364	585.116	2.60	5.4	51.85	3.621	2.952
0.36	8.353	582.811	2.61	5.42	51.85	3.617	2.949
0.42	8.347	581.556	2.63	5.43	51.56	3.614	2.946
0.6	8.342	580.511	2.64	5.43	51.38	3.612	2.944

2.2 IR spectra

Description and interpretation of IR spectra are given in [18]. As we know, two absorption bands corresponding to the M-O connection of metal ions of tetrahedral and octahedral sublattices should be observed in the IR-spectra of ferrite nanopowders. Both bands are observed in the spectra of our samples. It is known the frequencies of the oscillations are related to the force constants, and using these relationships, we were able to calculate the Debye temperature at different concentrations according to the Waldron model. The results are given in table 2 [17, 18, 19].

Table 2

Absorption frequencies (ν_1, ν_2), force constants (k_T and k_O) of IR spectra of $Ni_{0.4}Cu_xZn_{0.6-x}Fe_2O_4$(x=0-0.6) ferrites with different concentrations and Debye temperature calculated according to the Waldron model.

X	ν_1 (cm^{-1})	ν_2 (cm^{-1})	ν_{mean} (cm^{-1})	k_{T*10^5}	k_{o*10^5}	$k_{mean*10^5}$	ν_1-ν_2 (cm^{-1})	θ_{DW} (K)
0	563.74	476.43	520.09	2.33	1.66	2	87.31	748
0.24	554.10	475.33	514.75	2.25	1.66	1.96	78.77	740
0.3	570.06	485.86	527.96	2.38	1.73	2.06	84.2	759
0.36	552.12	481.87	517.025	2.24	1.7	1.97	70.31	743
0.42	571.96	471.20	521.58	2.4	1.63	2.02	100.76	750
0.6	587.00	481.62	534.31	2.53	1.7	2.12	105.38	768

3.3 Elastic properties

We can determine the elasticity parameters of $Ni_{0.4}Cu_xZn_{0.6-x}Fe_2O_4$ (x=0-0.6) nanoferrite powders with different concentrations by means of IR-spectral analysis [19,20]. C_{11} and C_{12} hardness coefficients calculated according to different concentrations of $Ni_{0.4}Cu_xZn_{0.6-x}Fe_2O_4$ (x=0-0.6) nanoferrite powders are given in table 4. According to the table, the value of these parameters varies depending on the relationship between Cu^{2+}, Zn^{2+}, Fe^{3+} cations and O^{2-}anion. Based on C_{11} and C_{12} coefficients, Young's modulus (Y), stiffness modulus (n) and bulk density modulus (B) were calculated and listed in table 3.

Table 3

Hardness coefficients (C_{11} and C_{12}), Poisson's ratio (σ), elastic wave velocities (ν_l, ν_s, ν_m), Young's modulus (Y), volume compression of $Ni_{0.4}Cu_xZn_{0.6-x}Fe_2O_4$ (x=0-0.6) ferrites at different concentrations modulus (B), stiffness modulus (n) [20-22].

x	C_{11} (GPa)	C_{12} (GPa)	σ	ν_l (m/s)	ν_s (m/s)	ν_m (m/s)	Y (GPa)	B (GPa)	n (GPa)
0	238	41	0.147	6670	4301	5486	226	107	99
0.24	234	41	0.148	6602	4250	5426	222	105	97
0.3	246	43	0.149	6750	4324	5537	233	111	101
0.36	236	41	0.149	6598	4231	5415	224	106	97
0.42	242	43	0.150	6676	3742	5209	229	109	76
0.6	254	45	0.150	6839	3838	5339	240	115	80

As the concentration of Cu^{+2} ion increases, the same trend is observed. The sharpest increase is observed at x=0.3 and 0.6 values. Also, longitudinal and transverse wave velocities (v_l, v_s) and average velocity (v_m) were calculated depending on Cu ion concentration [19].

RESULTS

In this study, $Ni_{0.4}Cu_xZn_{0.6-x}Fe_2O_4$ (x=0-0.6) nano ferrite powders were synthesized by thermal method. X-ray spectra show that ferrite structures with pure, single-phase spinel structure were obtained. It was determined that the lattice parameter decreases as the Cu^{+2} ion concentration increases. This is explained by the small radius of the replaced ion. IR spectra confirm the results of X-ray structural analysis. Spectral lines (478-600 cm^{-1}) characteristic of spinel ferrites are observed in the IR spectra of all samples. According to the results obtained based on these two methods, the longitudinal, transverse and average speed of the elastic wave propagating in the crystal lattices of these samples (v_l, v_s, v_m), volume compression modulus (B), strength modulus (n), Young's modulus (Y), Poisson's ratio (σ) and Debye temperature (θ_{Dw}) were calculated.

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