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Research Article

Influence of Magnon-phonon Interaction on Ultrasound Absorption in Nanocomposite Materials

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Abstract: Absorption of ultrasound in nanocomposite materials during the application of external magnetic field was considered in this study. Interaction of acoustic waves with crystal lattices of condensed media depends on many factors such as the type of the crystal lattice, Debye temperature and temperature of the condensed medium, as well as Debye frequency and frequency of the ultrasound. Debye frequency and Debye temperature determine elasticity of the crystal lattice and, consequently, its sound absorbing properties. For measurement and calculation of the coefficient of ultrasound absorption it is necessary to estimate the interaction of acoustic phonons with thermal phonons and electrons of investigated crystalline material. Application of external magnetic field on given material leads to the appearance of magnons that interact with the crystal lattice. As a result the ratio "acoustic phonon-thermal phonon" and, accordingly, sound absorption quantitatively increase. Experimental results obtained in this study coincide with the general picture of sound absorption obtained by other researchers, for example, in the measurement of acoustomagnetic resonance and in concept of magnon-phonon interaction.

Keywords: Magnetic moment, magnetic nanocomposite materials, magnon, nanoparticle, phonon, ultrasound absorption

INTRODUCTION

Ultrawave absorption in the crystal lattices occurs as result of phonon interactions and electron-phonon interactions. In the first case, acoustic phonon interacts with thermal phonon of lattice oscillations of the crystal lattice. Sound absorption coefficient depends on the rate of decrease of the phonons of sound mode in the collision of acoustic and thermal phonons. During such interaction acoustic phonon disappears and third phonon is formed. In the second case, acoustic phonon is absorbed by free electron. Phonon-phonon interactions are distinctive for the crystal lattices of dielectrics. Electron-phonon interactions take place in the crystal lattices of metals. For the latter phonon-phonon interactions also cannot be excluded.

Ultrasound absorption in the crystal lattices of condensed media on the basis of three-phonon theory of Landau and Rummer was considered in Omarov *et al.* (2014). Investigations showed that sound absorption has a different nature for the crystal lattices of dielectrics and metals. From the calculation of coefficient of ultrasound absorption in the crystal lattice based on the phonon theory (Omarov *et al*., 2014), it follows that the coefficient of ultrasound absorption depends on the energy of the acoustic phonon, on the number of thermal phonons of lattice vibrations, on the temperature and the type of crystal lattice. It was found that increase in temperature and type of crystal lattice appreciably affect ultrasound absorption.

Therefore, nanocomposite materials will also be dependent on the type and temperature of the crystal lattices of nanoparticles that form the basis of this material. Sound absorbing properties of nanoparticles can be controlled by changing their composition. Application of alternating magnetic field on nanocomposite material leads to additional increase in ultrasound absorption (Lotonov *et al*., 2006; Kezilebieke *et al*., 2013; Nyssanbayeva and Omarov, 2015).

Investigated phenomenon of magnon-phonon interaction in nanomaterials may be taken into account in the construction of a number of elements of computing and other high-precision electronic equipment. Authors also do not exclude that given nanocomposite materials can change their composition of nanoparticles in radiation fields. Change in the composition of nanoparticles can in turn affect their magnetic properties, such as magnetic viscosity. Change in magnetic properties influences on performance of computing systems. In other cases, on the contrary, increase of magnetic memory is required.

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Table 1: Particle sizes obtained using XRD, lattice constants (a_0), maximums of magnetization (M_s), coercivity (H_c), ratio of residual magnetizations (M_r/M_s) for nanoparticles of $Co_xNi_{1-x}Fe_2O_4$

Concentration x	Size D_{xrd} (nm)	a_0 (A^0)	M_s (emu/g)	H_c (Oe)	M_r/M_S
0.0	36.5	8.349	51.465	56.50	0.121240
0.1			54.830	139.51	0.097910
0.2	36.2	8.352	56.476	496.93	0.072280
0.3			57.910	1316.40	0.028180
0.4	33.4	8.357	59.076	2008.20	0.019360
0.5			61.945	2941.90	0.014260
0.6	25.1	8.374	62.659	33.05	0.013130
0.7			64.657	2780	0.015220
0.8	24.5	8.392	67.492	1797	0.022350
0.9			69.705	1260	0.022658
1.0	20.4	8.405	73.383	964	0.030220

Table 2: Velocity of longitudinal acoustic wave

Sample	Ω_1 = 35 kHz	Ω_2 = 45 kHz	Ω_3 = 65 kHz
$Co_xNi_{1-x}Fe_20_4$	v_1 = 350 m/sec	V_2 = 360 m/sec	V_3 = 380 m/sec
	α = 470 (dB/m)	α = 780 (dB/m)	α = 1100 (dB/m)

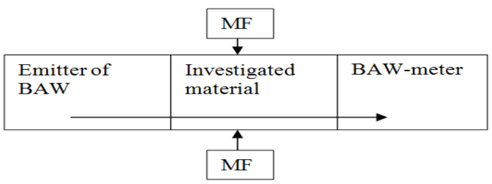

Fig. 1: Schematic diagram of the measurement of velocity and attenuation of acoustic wave
BAW: Bulk acoustic wave; MF: Magnetic field

As can be seen, researches in this field are currently relevant. So, main goal of this study is to investigate effect of magnon-phonon interactions on ultrasound absorption in nanocomposite materials.

MATERIALS AND METHODS

Nanocomposite material $Co_xNi_{1-x}Fe_2O_4$ (Mutila *et al*., 2012), synthesized by hydrothermal method using Polyethylene Glycol (PEG), placed in external magnetic field (Nyssanbayeva and Omarov, 2015) was considered as the object of investigation. Composition of nanoparticles in considered nanocomposite material obtained using TEM and XRD are shown in Table 1 (Nyssanbayeva and Omarov, 2015).

Schematic diagram of the experiment on measurement of the velocity and attenuation of acoustic waves in the presence of external magnetic field in the investigated nanomaterial is shown in Fig. 1.

Evaluation of sound absorption α in (dB/m) units, calculated taking into account elastic modulus C_{11} and viscosity coefficient η_{11}, can be carried out using following formula:

$$\alpha\left(\frac{dB}{m}\right) = -8.66\,\frac{\omega^2\eta\sqrt{\rho}}{\sqrt{2C_{11}^3\cdot(1+\omega^2\frac{\eta_{11}^2}{C_{11}^2})}} \quad (1)$$

where,

C_{11} = Elastic modulus
η_{11} = Longitudinal coefficient of viscosity
ρ = Density of investigated material
ω = Frequency
α = Attenuation coefficient

RESULTS AND DISCUSSION

Results of the measurement of velocity of longitudinal acoustic wave are shown in Table 2.

From the calculation of coefficient of ultrasound absorption (Omarov *et al*., 2014) it also follows that ultrasound absorption is directly proportional to the velocity of longitudinal acoustic wave. Also during the calculation of the coefficient of ultrasound absorption in dielectrics its dependence on temperature has a resonance character. The measurements were performed for nanoparticles with size of x = 0.6.

Obtained results confirm increase in velocity of the acoustic wave with frequency of sound and with increase in the amount of external magnetic field. Sound absorption is also increasing. Obtained data also confirm the results from measurements and evaluation of sound absorption of elastomers in a magnetic field (Lotonov *et al*., 2006; Kezilebieke *et al*., 2013).

Experimental data show that increase in frequency of excited bulk acoustic wave lead to increase in longitudinal elastic modulus of the investigated material. Magnetic properties of nanomaterial depend on the structural composition of the nanoparticles. For example, for $Co_xNi_{1-x}Fe_2O_4$ measured magnetic characteristics have the following form (Fig. 2) (Mutila *et al*., 2012).

In Omarov *et al*. (2015) it was noted that quantitative composition of the investigated material may change in radiation fields, for example, during the irradiation by gamma rays. Increase in the concentration of cobalt leads to a monotonic increase in M_s. The reason lies in the substitution of Ni^{2+} ions with magnetic moments of 2 μB by Co^{2+} ions with larger magnetic moment of 3 μB. Thus increase in concentration of Co^{2+} leads to increase in the total magnetic moment of the synthesized $Co_xNi_{1-x}Fe_2O_4$ nanoparticles and increase in coercivity of magnetic material, which is not always desirable. Increased

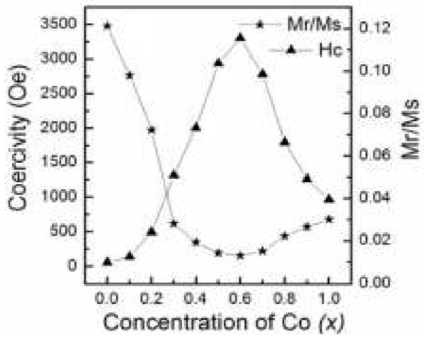

Fig. 2: Magnetic properties of $Co_xNi_{1-x}Fe_2O_4$ depending on concentration of Co

coercivity may influence on the composition of magnons and respectively, on the ultrasound absorption.

CONCLUSION

Measurement of the velocity of bulk acoustic wave in nanocomposite materials showed that during the application of external magnetic field the speed of sound decreases. Increase in velocity of sound wave (1) in the calculation formula indicates the increase in sound absorption. Application of external magnetic field on the magnetic field dependent materials changes their acoustic characteristics, including sound absorbing properties.

Quanta of magnetic energy (magnons) absorbed in the investigated material increase the vibrational heat energy of crystal lattice and, consequently, the number of thermal phonons. This, in turn, influence on further interaction of acoustic phonons with thermal phonons and on increase in sound absorption.

The concept of the authors to consider the physical nature of sound absorption as a result of indirect magnon-phonon interaction was confirmed by experimental results obtained by measurement of the acoustic characteristics of nanocomposite materials placed in a magnetic and ultrasound field.

Results of the investigation of acoustic characteristics of nanocomposite materials can be used for development of magnetically controlled signal processing devices, in radiolocation, computers, automation and other radio technical directions.

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