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Short Communication

Method for the Determination of Magnetoelastic and Elastic Constants of Weak Ferromagnets

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Excitation of flexible vibrations in weak ferromagnets plaes in an external magnetic field is experimentally investigated. It is proposed to use dependence of resonant frequencies on a magnetic field for tunable source of flexural vibrations.

Keywords: Flexible vibrations; Lamb waves; Weak ferromagnets; Resonant frequency, Iron borate, Magnetoacoustic interaction, Magnetoelastic constants.

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1. INTRODUCTION

Wave spectra of magnetic films and plates that are used as memory cells, specifically, in MRAM cells [1, 2], are being intensively investigated. The dominant role in forming those spectra is played by the dynamic interaction among magnetic, electric, and acoustic subsystems, which in real-world components occurs under the influence of restricting surfaces [3, 4]. In this case it is important to know the appropriate resonant frequencies and control them. From the investigation of interactions that accompany dynamic nonlinear processes in restricted media with different physical states under the external action of various intensity levels it is possible to design nonlinear components and devices noted for enhanced service features and functionalities.

The action of surfaces produces novel types of acoustic waves [5], such as shear waves, Raleigh-Lamb waves, and others [6], associated with a magnetic subsystem. It is shown in [7] that an external magnetic field may suppress the amplitudes of flexural Lamb waves for a ferromagnetic plate. Such an additional rigidity changes the dispersion of flexural waves. If one goes to orientation phase transitions uniformly magnetized crystal plate may be divided into domains [8], and in multilayered structures novel wave types appear [9].

A number of magnets are transparent in the visible and near infrared range, which allows for the use of optical techniques not only for recording, reading, and data processing but also for the study of those magnets. A special place among them is occupied by antiferromagnets with a low magnetic moment angularity of sublattices (weak ferromagnets). Among them are orthoferrites, iron borate, hematite, and others [10], a number of unique features of which, specifically, magnetooptic, make them promising for making use in high-speed data processing devices. Those crystals are noted for both their strong magnetoacoustic coupling rendering the dynamics of domain walls [10, 11] and acoustic waves [12] nonlinear and the ultra-fast dynamics of a magnetic subsystem [13].

Earlier [14, 15] it was shown that the domain wall motion in weak ferromagnet plates, yttrium orthoferrite, is accompanied by the excitation of flexural Lamb waves, whose amplitude drastically increases at resonant frequencies dictated by the sample size. Such waves were shown to exchange energy [16-21]. It is necessary to know the effect of a magnetization reversal field on the resonant frequencies of those waves because they may appear also in other ferromagnets. We are not aware of the experimental work corroborating the inferences of works [3, 7, 8] for weak ferromagnets.

2. EXPERIMENTAL

We have experimentally investigated the Lamb waves in uniformly magnetized iron borate plates in an external magnetic field. Samples as plane-parallel plates around 150 μm in thickness and a cross-sectional dimension of 2-3 mm were used. Plate faces that coincide with the epipolar plane were not mechanically treated. Flexural vibrations of plates (the Lamb waves) were exited with a piezoceramic plate at whose edge a sample was fixed (Fig. 1). Voltage with an amplitude of 15 V and frequencies up to several MHz was fed from a harmonic vibration generator to the piezoceramic plate.

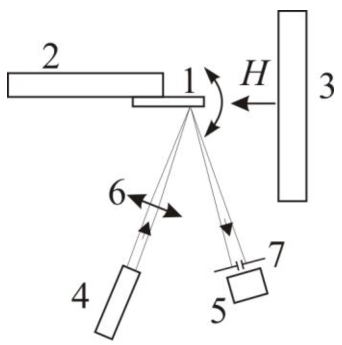

Fig. 1 – Experimental setup: 1 – FeBO3 sample, 2 – piezoceramics, 3 – permanent magnet, 4 – He-Ne laser, 5 – photodiode, 6 – lens, 7 – diaphragm

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To measure the frequency dependencies of the amplitude and phases of flexural waves the dark-field method similar to that described in [16] was used (Fig. 1). The magnetic field that was oriented in the epipolar plane was produced by a permanent magnet which had larger dimensions than the samples and was dependent on the distance to them.

The determination of the excited vibration types was carried out in the examination of the way in which the deviation angle of the reflected laser radiation was distributed across the sample surface.

3. RESULTS AND DISCUSSION

The vibration amplitude drastically increased at resonant frequencies dependent on the dimension of a free portion of the plate.

Fig. 2 shows amplitude-frequency characteristics (a) and phase-frequency characteristics (b) for flexural vibrations collinear to the magnetic field near one of the resonant frequencies 87 kHz in magnetic fields $H = 6{,}3$ Oe and 556 Oe. It is seen that with an increase in the external magnetic field from 6,3 to 556 Oe the resonant frequency increases as well, which is in accord with inferences of [3, 7, 8] where it is shown that the magnetoacoustic interaction brings about an increase in the flexural vibration frequency in a magnetic field.

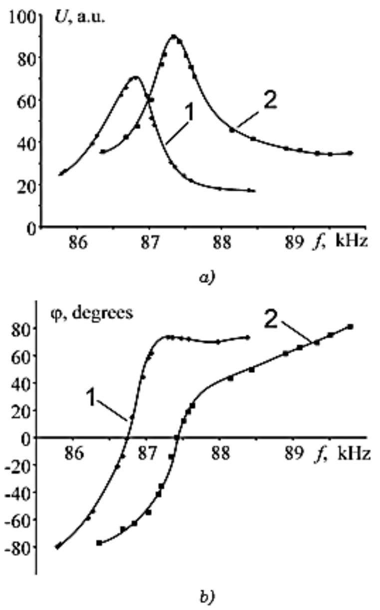

Fig. 2 – Amplitude-frequency characteristics (a) and phase-frequency characteristics (b) in fields $H = 6{,}3$ Oe (1) and 556 Oe (2)

The dispersion law of flexible vibrations in weak ferromagnets plates in linearized form can be represented as follows [3]:

$$Y = f_\infty^2 + \left(f_0^2 - f_\infty^2\right)X ,$$

where: $Y = f^2$, f – frequency of flexible vibrations; f_0, f_∞ – limiting frequencies at $H = 0$ and $H \to \infty$, respectively. f_0 depend on the elastic constants, f_∞ depend on the magnetoelastic constants.

$$X = \left(1 + 2mH/H_a\right)^{-1}$$

here: m – unit vector of the magnetization, H_a – anisotropy field.

Fig. 3 depicts the linearized characteristics Y(X) by measurements and direct constructed by the method of least squares for hematite plates with thicknesses of 120 microns (a) and 85 microns (b). According to these data with good accuracy can be determined a combination of magnetic parameters and measured constants.

Using samples of the plates, cutted in different crystallographic planes and exciting flexural vibrations with different directions of the wave vector, we can get the system equations for the corresponding combinations f_0, from which the elastic constants can be determined. Using these constants and system equations for f_∞, we can define magnetoelastic constants.

Thus, the proposed method allows to determine the elastic, magnetic and magnetoelastic constants. The results of measurements are sensitive to the quality of only two processing surfaces bounding plate, and do not depend on the size and shape of samples in other coordinates.

This method can be used for measurement of constants of nanoscale heterostructures.

The results obtained are of not only fundamental interest making a deeper understanding of physics of the magnetic interactions between magnetic and acoustic subsystems but also may find practical applications. It is expedient, in our opinion, to continue study with other magnetic materials.

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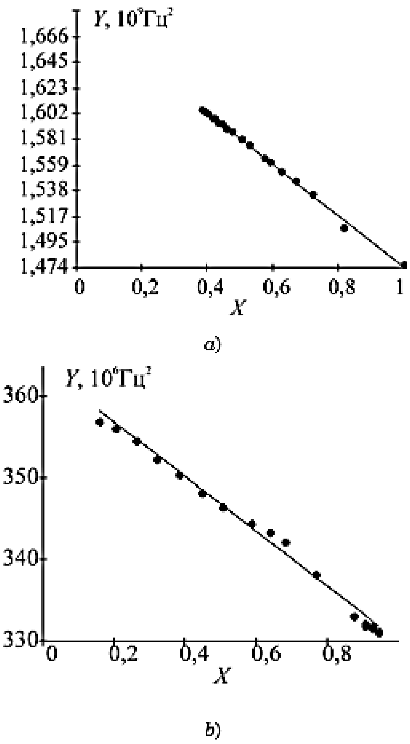

Fig. 3 – Linearized characteristics Y(X) for hematite plates with thicknesses of 120 microns (a) and 85 microns (b)

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