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# Magnetoacoustic effects of $CoFeB/SiO_2$ composite films with different magnetic structures excited by nanosecond laser pulses

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Experiments on excitation of elastic pulses by nanosecond laser pulses were carried out, and their propagation in the $CoFeB/SiO_2$ composite films with different magnetic structures was studied. The highest amplitude of the excited elastic pulses was observed in films with the stripe magnetic structure. Maxima of the amplitude and power of the elastic pulse spectrum components were found at the frequencies of 61 and 72 MHz for the stripe-magnetic-structure films; the maxima are associated with oscillations of the structureś magnetic stripes excited by the nanosecond laser pulse. The study has shown that a bilayer lavsan−composite film can play the role of an acoustic resonator for excited elastic pulses at the frequencies under consideration.

**Keywords:** elastic and laser pulses, composite metaldielectric films, magnetic structure, magnetic field.

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In recent years, acousto-optical methods have been increasingly used in physical studies of various magnetic materials [1–5]. Acousto-optical methods have undeniable advantages over conventional ultrasonic methods: contactless excitation of elastic oscillation pulses and their significant broadbandness [4]. Investigation of mechanisms for exciting ultrashort elastic pulses by optical pulses in magnetic films are of great interest in view of both developing theoretical concepts of nonlinear physics and solving applied problems of acousto-magnetic electronics by using up-to-date lasers and acoustic devices [1,5]. In the case of optical excitation, several basic processes of elastic oscillation pulse generation are typically taken into account; among them, the most preferable one is the thermal mechanism providing simultaneous generation of magnetic and elastic oscillation pulses and their interaction [1,3,5]. In those studies, researchers paid especial attention to excitation of ultrashort elastic pulses and to their interaction with magnetic structures [1,5]. Interest in studying composite metaldielectric films is caused by the fact that in these films different magnetic structures may arise depending on the metal alloy concentration [6]. In [6], a minimum of the impedance modulus was revealed for the $CoFeB/SiO_2$ composite films with the stripe magnetic structure at the frequency of about 2.3 GHz; the amplitude and position of that minimum depended strongly on the magnetic field. The presence of the microwave impedance minimum and magnetic-field dependence of the minimumś position and amplitude for the $CoFeB/SiO_2$ films with the stripe magnetic structure is expected to significantly affect the filmsḿagnetoelastic properties, which should have manifested itself also in the experiments we have planned. In this work, we have investigated the effect of magnetic field on the parameters of elastic pulses propagating in the $CoFeB/SiO_2$ composite films on polymer substrates with different magnetic structures.

The objects of research were composite metal-dielectric $CoFeB/SiO_2$ films on lavsan substrates 30 $\mu$m thick. The composite films were obtained in vacuum of 1.5 $\mu$Pa by argonion bombardment of targets made of metal alloy $Co_{0.44}Fe_{0.36}B_{0.2}$ and dielectric $SiO_2$. The filmsélemental compositions and thicknesses were determined with scanning electron microscope TESCAN MIRA 3 LMH [6]. The film thickness was derived from the images of butt ends of composite film pieces scraped off from the lavsan substrate. Composite film *D* 0.69 $\mu$m thick had the following elemental composition (in atomic fractions): Co — 0.25, Fe — 0.23, B — 0.16, Si — 0.12, O — 0.24. Elemental composition of the other composite film *G* 0.86 $\mu$m thick was as follows: Co — 0.29, Fe — 0.26, B — 0.12, Si — 0.11, O — 0.23. Magnetic phase contrast images of the film surfaces were obtained with atomic force microscope NTEGRA PRIMA (NT-MDT, Russia) [6]. The microscope was equipped with a silicone probe coated with a 40 nm thick CoCr magnetic alloy. Resolution of different uniform magnetic regions was 20 nm. During shooting, a phase shift was detected for oscillations of the cantilever with a magnetic probe mounted above the film surface section, which depended on the strength of the magnetic probe interaction with this section. Analysis of the obtained magnetic phase contrast images of the film surfaces showed that the film *D* granular-percolation structure had the form of disordered weakly and strongly magnetized regions of various sizes and shapes (Fig. 1, *a*). The granular-percolation structure of

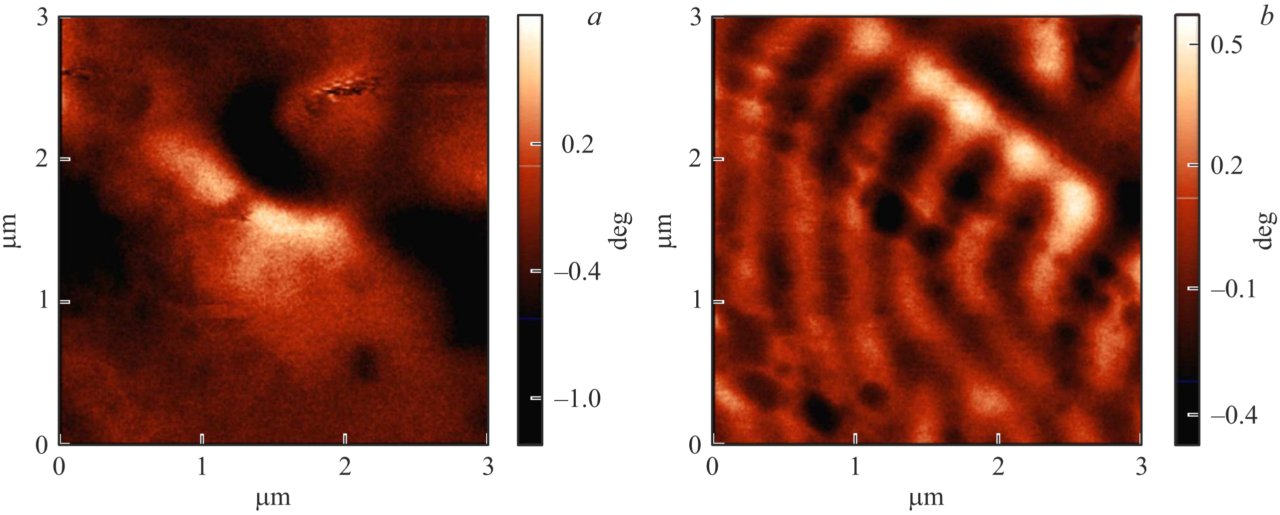


**Figure 1.** Magnetic phase contrast images of films $D$ ($a$) and $G$ ($b$). The right panel presents on the vertical color scale the phase shifts (in degrees) of oscillations of the cantilever with a magnetic probe. The colored figure is given in the electronic version of the article.

film $G$ included a stripe magnetic structure with adjacent oppositely magnetized stripes $0.4\,\mu$m in period and more than $2\,\mu$m in length (Fig. 1, $b$).

In the experiment, the samples to be studied were placed in the 30 mmwide electromagnet gap in which magnetic field with the induction of 0 to 0.26 T was created. The magnetic field was directed in parallel to the film plane. Elastic pulses were excited in composite films on lavsan substrates by optical laser pulses with the wavelength of 532 nm, duration of 1.5 ns, and repetition frequency of 1 Hz [4]. Energy density of the sample irradiation pulse did not exceed $E \leqslant 10^{-2}$ J/cm$^2$. The irradiation area was restricted by a diaphragm 4 mm in diameter [7]. The laser pulse was directed to the test film placed on piezoelectric ceramic plate CTS-19 2 mm thick. The acoustic contact between the film and piezoelectric ceramic plate was provided by pressing the film to the plate by an optical glass with the aid of transformer oil [4,7]. The electrical signal was picked up from the piezoelectric transducer and recorded by oscilloscope LECROY with the transmission bandwidth of 300 MHz. To reduce the piezoelectric transducer electromagnetic interference and match it with the oscilloscope, it was loaded with a resistance of $50\,\Omega$. The elastic pulse amplitude was proportional to that of electrical pulses picked up from the piezoelectric transducer. The error in determining the electrical signal amplitude and duration was no more than 5%. The oscilloscope was synchronized by electrical pulses from the photodetector, which were created by laser pulses. All the measurements were performed at room temperature.

Fig. 2 presents time dependences of amplitudes of electrical signal $U(t)$ from the piezoelectric transducer; the signal was induced by elastic pulses passing through composite films $D$ and $G$ in the zero magnetic field and in the magnetic field with $B = 0.2$ T. As Fig. 2, $a$ shows, amplitude of the elastic pulse excited by a laser pulse in film $G$ in the zero magnetic field is 3 times higher than that of a similar pulse in film $D$; this evidences that excitation of elastic pulses by the laser pulse in film $G$ with the stripe magnetic structure is much more efficient than in film $D$ with disordered magnetic structure. Dependences $U(t)$ presented in a larger time scale for the stripe-magnetic-structure film $G$ located in the zero magnetic field and in the field of 0.2 T exhibit a series of four elastic pulses (Fig. 2, $b$). The second and subsequent elastic pulses in such a series are acoustic pulses re-reflected from the boundaries of composite film $G$ and lavsan film (substrate). Longitudinal ultrasonic velocity in this bilayer lavsan–composite film was estimated taking into account the time interval of 15.2 ns between re-reflected pulses (Fig. 2, $b$) and appeared to be 4060 m/s. At such an elastic wave velocity, the lavsan film thickness $30\,\mu$m is equal to a half of elastic oscillation wavelength at the frequency of 67 MHz belonging to the spectrum of elastic pulse excited by the nanosecond laser pulse. Hence, the bilayer film consisting of a thick lavsan film and thin $CoFeB/SiO_2$ layer deposited on it may play the role of an acoustic resonator for the excited elastic waves.

Fig. 3 demonstrates the magneticfield dependences of the piezoelectrictransducer electric pulse $U(B)$ amplitude and power of components of the electric pulse $P(B)$ spectrum at the frequencies of 61 and 72 MHz for composite film $G$ with the stripe magnetic structure. Dependences $U(B)$ and $P(B)$ exhibit maxima of the amplitude and power of the electric pulse spectrum components at the frequencies of 61 and 72 MHz. Maxima of dependences $P(B)$ of the spectrum components at the frequencies of 61 and 72 MHz take place at different magnetic fields (5 and 7 mT); this indicates the resonant nature of excited magnetoelastic oscillations in film $G$ having the stripe magnetic structure. At high magnetic fields ($B > 30$ mT), dependences $U(B)$ and $P(B)$ have the form of slightly descending curves exhibiting minor oscillations. This means that in strong

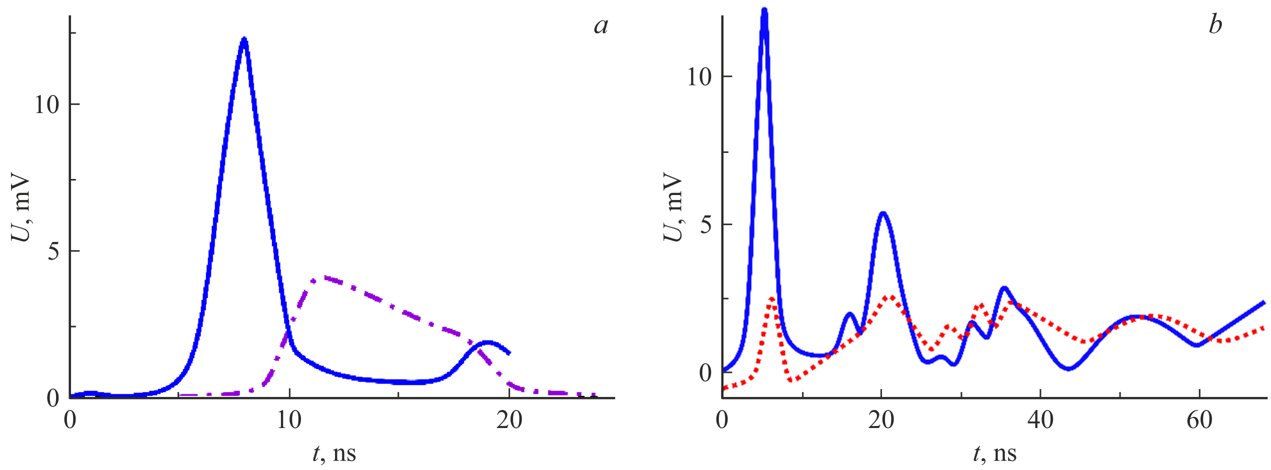


**Figure 2.** *a* — time dependences of the piezoelectric-transducer electric pulse amplitude for films *D* (dash-dotted curve) and *G* (solid curve) in the zero magnetic field; *b* — time dependences of the electric pulse amplitude for film *G* in the absence of magnetic field (solid curve) and in magnetic field of 0.2 T (dotted curve).

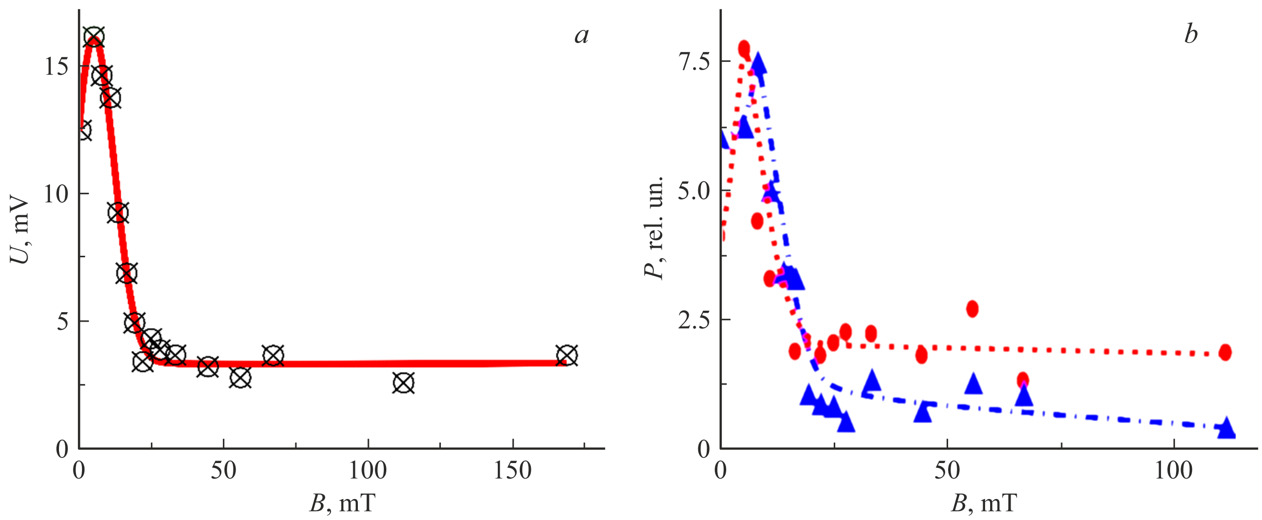


**Figure 3.** *a* — electric pulse amplitude dependence on magnetic field induction *B* for film *G*; *b* — dependences of the spectrum components'power at the frequencies of 61 MHz (dotted curve) and 72 MHz (dash-dotted curve) for film *G*.

magnetic fields elastic pulses are excited by laser pulses mainly due to the direct thermal effect with an insignificant contribution from magnetic oscillations. Note also that the maximum amplitude of the first elastic pulse in film *G* having the stripe magnetic structure is 4 times higher in low magnetic fields than in high magnetic fields with $B > 30$ mT. The low amplitude of the first elastic pulse for film *D* in different magnetic fields and for film *G* in a high magnetic field confirm a significant contribution to the elastic pulse amplitude from nanosecond-laser-pulse-induced oscillations of the stripe magnetic structure.

Thus, in this work we have studied the effect of the 0–0.26 T magnetic field on the amplitude and power of the 61 and 72 MHz spectrum components of elastic pulses excited in the $CoFeB/SiO_2$ composite films of different magnetic structures. Excitation of elastic pulses in composite magnetic films exposed to a nanosecond laser pulse occurs due to magnetoelastic oscillation pulses excited in them. The strongest magnetic field effect on the elastic pulse amplitude and spectrum, as well as the highest amplitude of the excited elastic pulse, is observed for the $CoFeB/SiO_2$ composite films with the stripe magnetic structure. A thick lavsan film whose thickness of 30 $\mu$m is close to one-half elastic wave length at 67 MHz can play the role of an acoustic resonator at the frequencies considered. In performing additional studies of films exposed to nano— and femtosecond laser pulses, it is promising to use the magnetoacoustic effects we have discovered for the $CoFeB/SiO_2$ composite films in order to examine the magnetic structure in thin magnetic films and to create an acoustic pulse amplifier and information processing devices.

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### Conflict of interests

The authors declare that they have no conflict of interests.

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