Nuclear magnetoelastic resonance in iron borate

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A resonant generation of magnetoelastic oscillations of ^{57}Fe in $FeBO_3$ was observed for the first time under NMR conditions by perturbing the samples with an alternating magnetic field or ultrasound at temperatures of 77 K and 4.2 K.

The generation of magnetoelastic oscillations, which stems from the oscillations of a bound system (electron-nuclear and phonon subsystems) and which has a threshold nature with respect to the alternating magnetic field H_1 or deformation ϵ of ultrasonic waves, occurs at certain values of the constant magnetic field H_0.

In the first case, we placed the samples with a natural concentration of the isotope ^{57}Fe (2.2 at.%) inside the coil of an NMR pulse spectrometer "Bruker SKLR-100" equipped with an acoustic pickup for the detection of ultrasonic waves from the sample. These waves were generated after the introduction of an rf pulse. We studied the behavior of free-induction signals and the frequency spectrum of the free-induction

signals after Fourier transformation as a function of the amplitude H_1, the magnitude and direction of $\mathbf{H}_0$, and the temperature T.

In the second case, we studied as a function of $\mathbf{H}_0$, ϵ, and T the damping (α) and the frequency spectrum ($\Delta\nu_{ac}$) of continuous and pulsed ultrasonic waves, which were excited by an external piezoelectric transducer and which were transmitted through the sample. In each experiment $\mathbf{H}_1$ and $\mathbf{H}_0$ were oriented in the (111) plane with $\mathbf{H}_1 \| \mathbf{H}_0$ or $\mathbf{H}_1 \perp \mathbf{H}_0$ and the wave vector of the ultrasonic waves $\mathbf{k} \| [111]$.

For $H_1 < 4 \times 10^{-2}$ Oe and $H_0 = 0$ the spectrum of the free-induction signals is comprised of two lines of width ~ 5 kHz. On the basis of the temperatures, frequency, and field dependences of the parameters of these lines we have identified them with the resonant oscillations of ^{57}Fe nuclei in domains and domain walls. As H_0 is raised to 40 Oe, with $\mathbf{H}_1 \| \mathbf{H}_0$, the line corresponding to the nuclei in the domain walls vanishes because of single-domain formation in the sample.

With an increase in H_1, we encountered a qualitatively new manifestation of magnetoelastic interaction. With $H_1 > 0.1$ Oe and $H_0 < 150$ Oe ($\mathbf{H}_1 \perp \mathbf{H}_0$, $T = 77$ K), the intensity of the free-induction signals decreased and coupled magnetoelastic oscillations appeared at the same time. These oscillations occur over a broad frequency spectrum (~ 1 MHz) consisting of single bands of width ~ 30 kHz. The spacing between these bands corresponds to the dimensional acoustic resonances in samples along the [111] axis. In this case, the intensity of the NMR line decreases to nearly zero (curve 1 in Fig. 1).

The same magnetoelastic oscillations were excited upon sweeping the continuous ultrasonic frequency with $\epsilon > 10^{-5}$. The spectrum of these oscillations, which is similar to the oscillations produced by rf excitations, can be explained by the presence of longitudinal and transverse types of oscillations which are caused by the excitation of

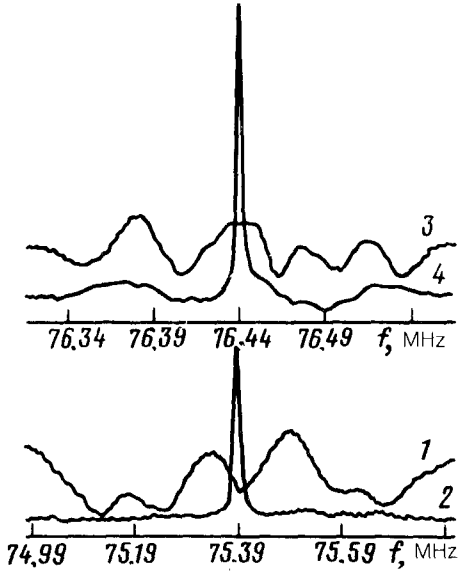

FIG. 1. Frequency spectrum of magnetoelastic oscillations. 1—$H_0 = 85$ Oe, $H_1 = 0.9$ Oe, $T = 77$ K; 2—$H_0 = 350$ Oe, $H_1 = 0.9$ Oe, $T = 77$ K; 3—$H_0 = 300$ Oe, $H_1 = 12$ Oe, $T = 4.2$ K; 4—$H_0 = 3.8$ kOe, $H_1 = 12$ Oe, $T = 4.2$ K.

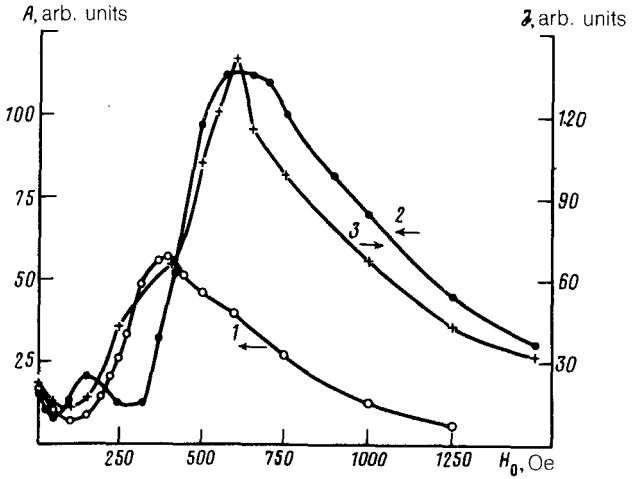

FIG. 2. The intensities of the magnetic component A and elastic component J of the magnetoelastic oscillations at NMR frequency versus H_0 at $T = 77$ K. 1—$H_1 = 0.9$ Oe; 2—$H_1 = 1.6$ Oe; 3—$\epsilon = 10^{-5}$.

the various parts of the sample bounded by domain walls. The validity of this assumption is borne out by the change in the spectrum of nonresonant magnetoelastic oscillations as H_0 is raised. An appreciable damping of transverse ultrasonic waves was observed under the same conditions.

With $\mathbf{H}_1 \perp \mathbf{H}_0$ and H_1 held constant in the range 0.1 Oe$\leqslant H_1 < 1$ Oe (77 K), the intensity of nonresonant magnetoelastic oscillations decreased with increasing H_0 and at certain values of H_0 we observed a resonant generation of a narrow spectrum of magnetoelastic oscillations at the NMR frequency (curve 2 in Fig. 1), whose field dependence is shown in Fig. 2 (curve 1). At $H_1 > 1$ Oe we observe the appearance of two regions of H_0, in which the resonant magnetoelastic oscillations increase (curve 2 in Figs. 2 and 3). Analysis of the free-induction-signal spectrum showed that nonresonant magnetoelastic oscillations, which occur after the completion of the rf pulse, damp rapidly (the relaxation time of the magnetoelastic waves is $\tau_{ph} \sim 1$ μs), giving way, as H_0 is raised, to resonant magnetoelastic oscillations which damp considerably slower ($\tau_p \sim 80$ μs) at each temperature. The resonant magnetoelastic oscillations occur in a narrow frequency range, ~ 13 kHz, which matches the width of the dimensional acoustic resonance with the center at the NMR frequency.

In a corresponding way, the damping of transverse modes in the magnetic fields that were used to apply rf pulses decreased (by a factor of seven or less) with increasing ϵ in the case of propagation of ultrasonic waves near the NMR frequency (curve 3 in Fig. 2). In other words, we observed an effect which is similar to the acoustic self-induced transparency.

It can thus be assumed that excitation of the samples by an alternating magnetic field or by ultrasound as a result of a strong magnetoelastic interaction gives rise to magnetoelastic oscillations whose broad spectrum is caused by the domains or domain

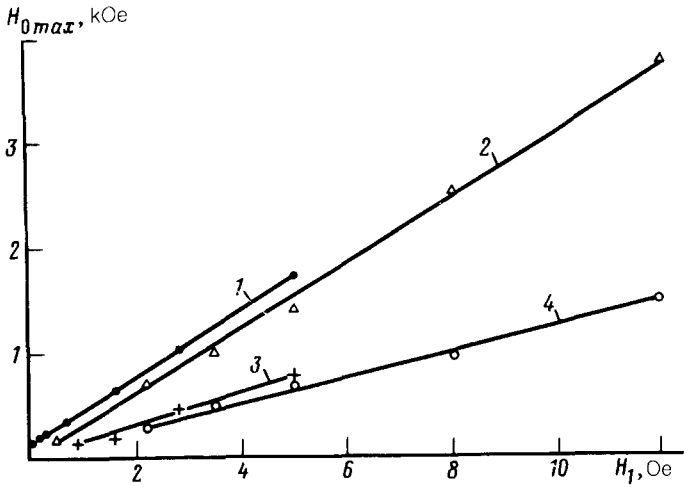

FIG. 3. $H_{0\max}$ versus H_1 at the following temperatures: 1,3—$T = 77$ K; 2,4—$T = 4.2$ K.

walls. These magnetoelastic subsequently cause transitions at the NMR frequency between nuclear spin levels by means of electron-nucleus interaction.

Since the process involving emission and absorption of a single phonon by a nucleus is given by $\sim H_E B_i / H_A$, where H_E is the effective field of the exchange forces, B_i is the magnetoelastic constant, and H_A is the anisotropy field, this process is dominant when these parameters have record-high values for iron borate.[2] The spectrum of nonresonant magnetoelastic oscillations in this case is transformed and its width is determined by the NMR line width. An additional intensification of the magnetoelastic oscillations occurs when the NMR frequency matches the dimensional resonances of the transverse ultrasonic oscillations. The participation of resonant spin transitions is also confirmed by the angular anisotropy of the amplitude of the ultrasonic oscillations which satisfy the acoustic NMR.

The dependence of $H_{0\max}$ at which there is a maximum intensification of the magnetoelastic oscillations at the NMR frequency when H_1 is held constant on the intensity of H_1 (Fig. 3) can be explained by the appearance of the orientational phase transition along the deformation, i.e., an abrupt spin reversal from the Zeeman configuration ($\mathbf{m} \| \mathbf{H}_0$) to an angular configuration [$< (\mathbf{m}, \mathbf{H}_0) \neq 0$]. An effect of this sort was observed previously only in the case of a static deformation in hematite.[3]

Since the magnetization oscillations follow the variable deformations in step, a periodic spin flip occurs in our case. A comparison of the results obtained by Ozhogin[3] with our data showed that the value of ϵ in the ultrasonic wave ($\sim 10^{-5}$) is completely in agreement with the condition for the dynamic orientational phase transition in the adjacent magnetic fields.

The effects which we have observed become more sharply defined as the temperature is lowered from 77 K to 4.2 K. Specifically, the amplitude and field resolution of

the magnetoelastic nuclear resonance peaks increase (curves 3 and 4 in Fig. 1) and a temperature-induced shift in $H_{0\,max}$ occurs (curves 2 and 4 in Fig. 3).

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