

Effect of "capture" of domain NMR frequencies on excitation of nuclear spin echo in domain walls of a YFeO_3 crystal

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It has been found experimentally that starting with a certain value of the external magnetic field directed along the axis a , the spin echo from ^{57}Fe nuclei in the domain walls of a YFeO_3 crystal begins to be formed at frequencies which correspond to NMR frequencies in the domain.

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We have shown in an earlier work⁽¹⁾ that when one uses the continual (static) method the NMR spectrum from ^{57}Fe nuclei located within the domain walls in a YFeO_3 crystal consists of two resonance lines at frequencies ν_{\max} and ν_{\min} (Fig. 1, curve 1) which correspond to the nuclei at those parts of the domain walls where there is a maximum density of distribution of spins in the angle θ that determines the orientation of the weak ferromagnetic moment in the plane ac relative to the rhombic axis c . The frequencies ν_{\max} and ν_{\min} are found from the condition $d\nu(\theta)/d\theta = 0$, where the function $\nu(\theta)$ takes into account the anisotropy of the local NMR frequency within the domain walls. As the result of singularities of the magnetic symmetry of orthoferrires the function $\nu(\theta)$ for $0 < \theta < \pi/2$ has two branches⁽²⁾:

$$\nu(\theta) = \nu_0 (1 - \alpha \sin^2 \theta \mp \beta \sin 2\theta) \pm (\gamma/2\pi) H_a \cos \theta, \quad (1)$$

where α and β are phenomenological constants of the hyperfine interaction, ν_0 is the NMR frequency in the domain, and γ is the nuclear gyromagnetic ratio. In (1) the component H_a of the external magnetic field along the rhombic axis a has been taken into account. It was shown in Ref. 1 that at 77 K the following relationship holds: $\alpha = 2\beta = 5.58 \times 10^{-3}$. This means that the high-frequency line at the frequency $\nu_{\max} = 75.95$ MHz corresponds to nuclei located near the "edge" of the domain walls while the line at the frequency $\nu_{\min} = 75.35$ MHz corresponds to the nuclei close to the center of the wall. The NMR frequency in the domain ν_0 lies in the interval between ν_{\min} and ν_{\max} closer to ν_{\max} . In the spectrum obtained with the static method this is not manifested. Calculated⁽¹⁾ and experimental (for Co-substituted YFeO_3 (Ref. 3)) values of ν_0 at 77 K are confined within the frequency range 75.75–75.86 MHz.

The external constant field H_b directed along the axis b does not affect the NMR spectrum. On the other hand the field H_a causes convergence of the lines ν_{\max} and ν_{\min} up to their complete merging and subsequent smearing out.⁽¹⁾ The coordinates of the nuclei responsible for the resonance lines approach the center of the domain wall, as follows from the condition $d\nu(\theta)/d\theta = 0$. The shift of frequencies ν_{\max} and ν_{\min} in the field H_a according to the data of Ref. 1 is indicated in Fig. 2 by dashed lines (for

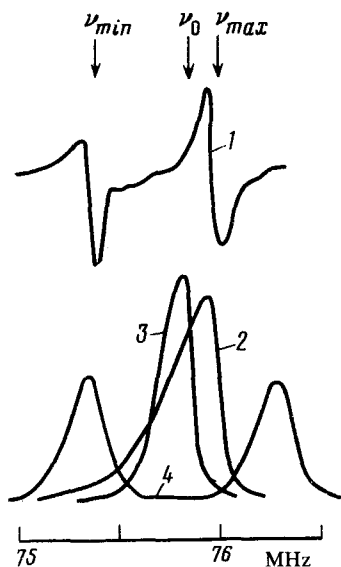


FIG. 1. First derivative of the NMR signal for a YFeO_3 crystal at 77 K (1) and spin echo spectra for the same crystal: $H_a = 0$ (2), $H_a = 0.8$ kOe (3), and $H_a = 4$ kOe (4).

more detailed description of the properties of NMR spectra within domain walls of orthoferrites see Refs. 1, 2, and 4).

This communication reports experimental results of observations of NMR within domain walls in the same hydrothermal YFeO_3 crystal as in earlier works but using a pulse method. The application of the spin echo method has been found to produce new effects.

Our study utilized the spectrometer ISSh-1-13 designed by the Special Designing Board of the Institute of Radio Engineering and Electronics, USSR Academy of Sciences. Steps were taken to produce low intensities of the rf field, which is necessary for observation of NMR spectra within the walls as they are usually characterized by very high coefficients of amplification. The maximum echo amplitude was achieved via a sequence of two short pulses of 1.5 and 2 μs with a 40 μs lag.

The dependence of the echo amplitude on the pulse frequency at 77 K and zero external field is shown in Fig. 1 (curve 2). The spectrum has an asymmetric shape with a rather gentle decline towards the low frequencies, and a maximum coinciding with the frequency ν_{max} . In the region of the frequency ν_{min} , where a second line is observed when using the static method, it was impossible to obtain an echo signal even though a spike of induction signal was visible after the pulse. Apparently, the impossibility of observing the echo in the region of ν_{min} can be attributed to the very short times of relaxation of the nuclei, which for the low-frequency line are located close to the center of the domain walls.

The longitudinal and transverse relaxation times in zero field were $T_1 = 500 \pm 100$ and $T_2 = 150 \pm 30$ μsec , respectively.

As with the static method, the external field H_b does not affect the shape, intensity, and relaxation characteristics of the spin echo spectrum. This is evidence that the

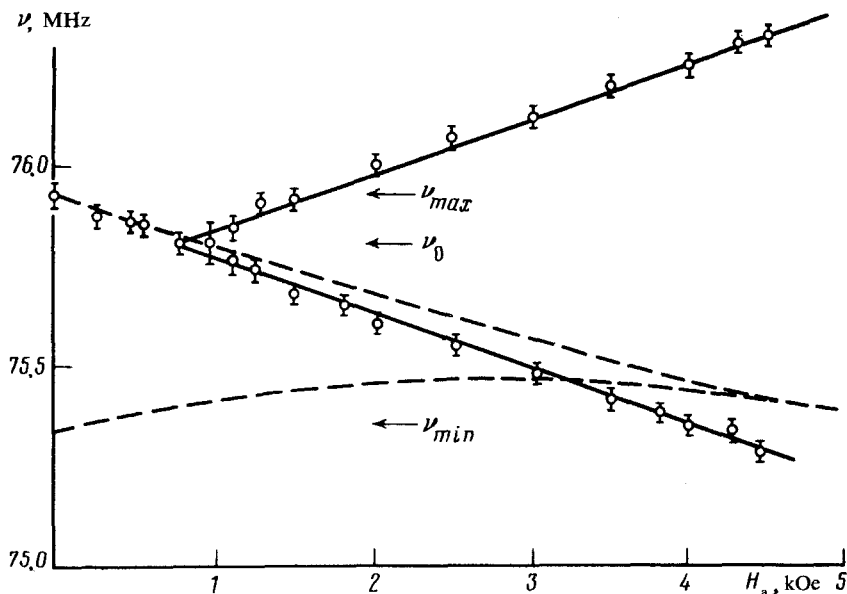


FIG. 2. Splitting of the intrawall spectrum of the spin echo for the YFeO_3 crystal at 77 K. The slope of straight lines corresponds to the gyromagnetic ratio for ^{57}Fe nuclei. The dashed lines show the shift of the lines of ν_{\max} and ν_{\min} on the basis of the data obtained with the static method.⁽¹⁾

rotation of the spins within the walls, in spite of their curved shape, occurs strictly in the ac plane (walls of the ac type), and the field H_b exercises no influence on the inner structure and dynamics of the walls.

In the field H_a the following is observed. As H_a is increased to 800 Oe the spectrum becomes more symmetric (Fig. 1, curve 3) and the maximum shifts towards lower frequencies in accordance with the trajectory for the "static" peak ν_{\max} (the upper dashed line in Fig. 2). Relaxation times are somewhat decreased in the process since the nuclei responsible for the signal are now located closer to the wall center. However, upon reaching the frequency of 75.8 MHz, which corresponds to the frequency ν_0 in the domain in the absence of external constant field, the spectrum begins to split into two lines which, at subsequent increase of H_a , are displaced in the same manner as would be observed if the signal proceeded from nuclei in the domains where the antiferromagnetic ordering of spins along the axis a takes place.

It is beyond doubt that the echo signals by their nature remain, nevertheless, located within the walls. This is supported by the following facts: 1) the echo is only observed when the rf field is directed along the "easy" axis c , and 2) the slightest disturbance of the exact orientation of the crystal in the constant field H_a that causes the appearance of a field component along the axis c leads to destruction of the domain walls and the echo signals.

Besides, if the signals originated from nuclei located deep inside the domains the splitting ought to have begun with zero field (the demagnetizing field does not play any role here as the result of the smallness of the spontaneous moment).

The relaxation times in all fields $H_a > 1$ kOe for both signals remain unchanged ($T_1 \sim 200\text{--}400 \mu\text{sec}$, $T_2 = 60 \pm 15 \mu\text{sec}$). This shows that the localization of the nuclei from which the echo signals originate remains constant with increasing H_a , in contrast to what is observed with the static method. The intensity of the split signals is also approximately the same (Fig. 2, curve 4). However, in the region of fields 2.5–3 kOe some decline of the echo amplitude for the low-frequency branch was observed which was probably due to the interaction of this branch with the low-frequency “static intrawall” branch ν_{\min} (the region of intersection with the lower dashed line in Fig. 2).

Thus, in the field H_a in the domain walls of a crystal of the weak ferromagnet YFeO_3 , conditions are created for appearance of an echo signal at frequencies corresponding to the NMR frequencies in the domain.

The results suggest the necessity of developing a new approach to investigation of the conditions under which the intrawall nuclear echo is formed in weak ferromagnets.

¹A. V. Zaleskii, A. K. Zvezdin, I. S. Zheludev, A. M. Savvinov, and A. F. Lebedev, *Phys. Status Solidi* (b) **73**, 317 (1976).

²A. K. Zvezdin, *Zh. Eksp. Teor. Fiz.* **68**, 1434 (1975) [*Sov. Phys. JETP* **41**, 715 (1975)].

³V. V. Vanchikov, A. V. Zaleskii, A. S. Karnachev, V. G. Krivenko, and E. E. Solov'ev, *Fiz. Tverd. Tela* **19**, 3640 (1977) [*Sov. Phys. Solid State* **19**, 2126 (1977)].

⁴A. V. Zaleskii and I. S. Zheludev, *At. Energy Rev.* **14**, 133 (1976).