Interaction of a moving domain wall in an orthoferrite with Lamb waves

M. V. Chetkin, A. P. Kuz'menko, S. N. Gadetskiĭ, V. N. Filatov, and A. I. Akhutkina
M. V. Lomonosov State University, Moscow

(Submitted 24 January 1983)
Pis'ma Zh. Eksp. Teor. Fiz. **37**, No. 5, 223–226 (5 March 1983)

It is shown that in the interval from the longitudinal sound velocity to the spin wave velocity, the stationary motion of a domain wall in yttrium orthoferrite occurs with a discrete set of velocities corresponding to the phase velocities of Lamb waves in the plate. The width of the constant-velocity intervals increases with decreasing specimen thickness.

PACS numbers: 75.60.Ch, 75.70. – i, 75.50.Gg

Investigations of the dynamics of domain walls (DW) in orthoferrites have shown that the DW velocity as a function of the pulsed magnetic field $V(H)$ has a series of features: intervals in which the velocity remains constant. These features are most distinct when the DW velocities coincide with the velocities of longitudinal and transverse sound[1,2] and with the spin-wave velocity[1,3] on the linear part of its dispersion curve. In addition, in the velocity range from the longitudinal sound velocity to the spin-wave velocity,[3–6] there is another series of regions in which the DW velocity is constant. In plates consisting of yttrium orthoferrite with a thickness of $\sim 100\ \mu m$, these regions had a width of the order of several tens of oersted.[4] In rare-earth orthoferrites, investigations of DW dynamics were restricted by the very high mobility of DW in these materials.[7] In this paper, we present the results of investigations of the function $V(H)$ for DW in yttrium orthoferrite plates with a thickness of 10, 25, and 40 μm. In this case, the width of the intervals of constant velocity on the curve of $V(H)$ turned out to be much larger than in specimens with large thicknesses. $YFeO_3$ plates were cut perpendicular to the optic axis and the [001] axis. We studied the dynamics of Bloch and Néel DW in these plates. In the experiments, we used a stroboscopic setup with parameters described in Ref. 8 and high-speed photography with 1-ns light pulses from an oxazine dye laser pumped by a nitrogen laser with a transverse discharge. In the latter case, two sequential positions of the dynamic domain structure were recorded on photographic film with a fixed time interval during a single passage of the DW through the specimen.

The fields required to rotate the magnetization vector of orthoferrites amount to tens of kilo-oersteds,[9] so that the DW dependence in weak ferromagnets such as orthoferrites can be studied in much higher fields than in ferrites-garnets and a number of other ferromagnets.

The curves of $V(H)$ for Bloch and Néel DW in a 25-μm $YFeO_3$ plate are shown in Fig. 1. For the Néel DW, the interval with constant DW velocity equal to 4×10^3 m/s is 250 Oe. This is much greater than observed previously in thicker specimens.[4,7] As V

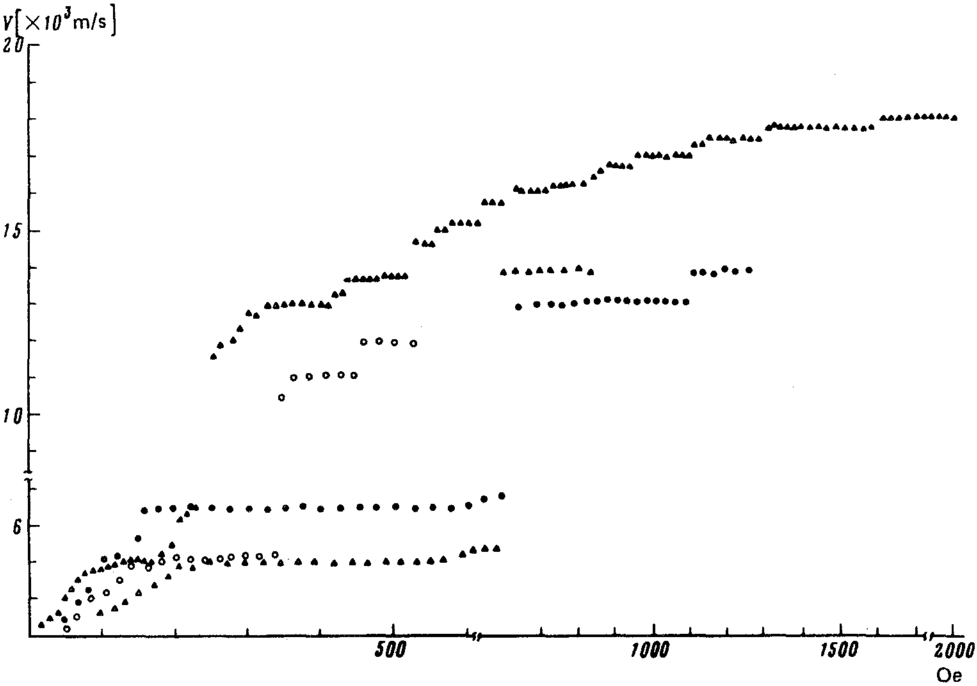

FIG. 1. The velocity of intermediate-type domain walls in $YFeO_3$ plates with thicknesses:(▲▲▲) 40-μm; (△△△) 10-μm, Néel boundaries, (*ooo*), and Bloch walls (●●●) in a 25 μm thick plate.

is increased, several more wide intervals with constant DW velocity are observed. For the Bloch DW, the feature with the transverse sound velocity is missing. This result corresponds to the theoretical prediction by Zvezdin *et al.*[10] and does not correspond to the experimental data in Ref. 2. The velocity is constant and equal to 7×10^3 m/s in an interval of 500 Oe. This is an order of magnitude greater than observed previously in specimens with large thicknesses cut perpendicular to the optic axis and the [001] axis. Figure 1 also shows analogous results for the 10-μm $YFeO_3$ specimen cut perpendicular to the optic axis. In this case, the interval with constant velocity equal to 4×10^3 m/s is 500 Oe. All of these results were obtained using the stroboscopic setup. In addition, Fig. 1 shows $V(H)$ for DW in a 40-μm $YFeO_3$ plate, perpendicular to the optic axis, obtained by the method of high-speed photography. It is evident that a larger number of regions with a constant velocity are formed than, for example, in a specimen with a thickness of 100 μm.[4,11] It is evident from Fig. 1 that the DW moves with a constant velocities, the transition between which occurs in a nearly jumplike manner.

The as yet unexplained additional regions of constant DW velocity occur after passage through the longitudinal V_l and transverse V_t sound velocity limits. This suggests that the dimensions of the plates studied must be taken into account for motion of DW in orthoferrites at supersonic velocities.[11] In plates and layers of finite dimensions, there exists a set of normal Lamb waves, whose phase velocities are higher than the velocities of longitudinal and transverse sound.[12] In the particular case of symmetrical waves we have.

$$V_S = V_l[1-(\pi n/kd)^2]^{-1/2} \tag{1}$$

Here d is the thickness of the plate, n is an integer, and k is the wave number.

The sequence of additional regions with constant DW velocity in $YFeO_3$ plates of all thicknesses can be satisfactorily described by an equation of the form (1); in so doing, it is necessary to include the entire set of symmetrical and antisymmetrical Lamb waves. The frequency of the Lamb waves, with which the DW interacts, is of the order of hundreds of MHz.

It was demonstrated in Ref. 8 that as the limit at the transverse-sound velocity is crossed, the motion of DW in orthoferrites ceases to be one-dimensional and stationary. The non-one-dimensionality of the motion in thin specimens arises at considerably higher fields than in thicker specimens. The distortion of the moving DW apparently begins along the thickness, while in thin specimens it is more difficult to distort the DW than in thick specimens, since the surface tension of DW is $\sigma\omega/R$. Figure 2(a) shows two sequential dynamic domain structures at room temperature in $YFeO_3$ specimens during a single passage of DW. The DW passes the darker section on the photograph over a time of 5 ns. It is clearly evident in Fig. 2(a) that, except for the special points on the intersection of neighboring semicircular sections of the DW, the DW moves with constant velocity. Figure 2(b) shows an analogous result at 100 K. The smoothing of the DW described in Ref. 8 is clearly evident. Figure 2(c) shows a photograph of a moving DW at the time of the transition to non-one-dimensional motion. The duration of the light pulse is 1 ns. At the beginning of the light pulse, the DW remains rectilinear, while in the remaining part of the pulse there was enough

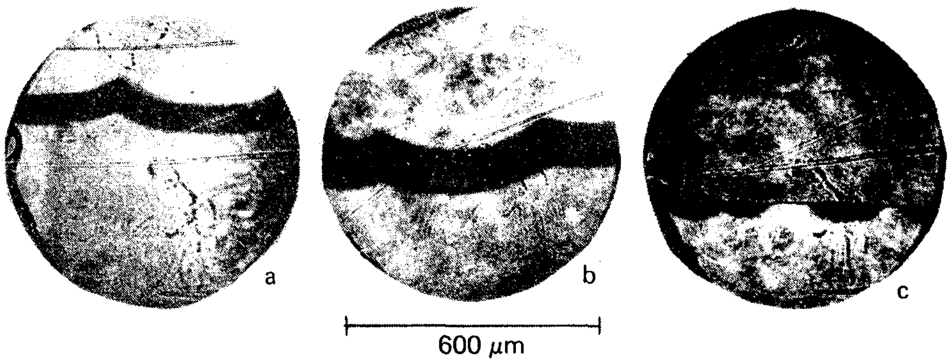

FIG. 2. Two sequential dynamic domain structures in a $YFeO_3$ plate with a thickness of 100 μm, cut perpendicular to the optic axis, obtained with a time interval of 5 ns during the single passage of a domain wall through the specimen: (a) at room temperature; (b) at a temperature of 100 K; (c) transition to nonuniform motion at 100 K. The duration of the light pulse was 1 ns.

time for large distortion to occur in the DW. It should be noted that if the temporal and spatial resolutions are used, the nonuniformity of the DW appears only in the transition through the transverse-sound velocity limit. To study the nonsteady-state of DW motion in orthoferrites, detected in Ref. 8, light pulses much shorter than 1 ns are necessary.

We are deeply grateful to A. S. Borovik-Romanov for discussing the results of this work.

[1]M. V. Chetkin, A. N. Shalygin, and A. De la Kampa, Fiz. Tverd. Tela **19**, 3470 (1977) [Sov. Phys. Solid State **19**, 2029 (1977)].
[2]C. H. Tsang, R. L. White, and R. M. White, J. Appl. Phys. **49**, 6052 (1970).
[3]M. V. Chetkin and De la Kampa, Pis'ma Zh. Eksp. Teor. Fiz. **27**, 168 (1978) [JETP Lett. **27**, 157 (1978)].
[4]M. V. Chetkin and A. I. Akhutkina, Zh. Eksp. Teor. Fiz. **78**, 761 (1980) [Sov. Phys. JETP **51**, 383 (1980)].
[5]A. K. Zvezdin, Pis'ma Zh. Eksp. Teor. Fiz. **29**, 605 (1979) [JETP Lett. **29**, 553 (1979)].
[6]V. G. Bar'yakhtar, B. A. Ivanov, and A. L. Sukstanskiĭ, Zh. Eksp. Teor. Fiz. **78**, 1509 (1980) [Sov. Phys. JETP **51**, 757 (1980)].
[7]M. V. Chetkin, A. I. Akhutkina, N. N. Ermilova, A. P. Kuz'menko, and Yu. S. Didosyan, Zh. Eksp. Teor. Fiz. **81**, 2206 (1981) [Sov. Phys. JETP **54**, 1172 (1981)].
[8]M. V. Chetkin, S. N. Gadetskiĭ, A. I. Akhutkina, Pis'ma Zh. Eksp. Teor. Fiz. **35**, 373 (1982) [JETP Lett. **35**, 459 (1982)].
[9]K. P. Below, A. K. Zvezdin, A. M. Kadomtseva, and V. Z. Levitin, Orientatsionnye perekhody v redkozemel'nykh magnetikakh [Orientational Transitions in Rare-Earth Magnetic Materials], Nauka, Moscow, 1979.
[10]A. K. Zvezdin, A. A. Mukhin, and A. F. Popkov, Preprint No. 108, FIAN, 1982.
[11]M. V. Chetkin, A. I. Akhutkina, S. N. Gadetsky, and A. P. Kuzmenko, J. Appl. Phys. **53**, 7864 (1982).
[12]I. A. Viktorov, Fizicheskie osnovy primeneniya ul'trazvukovykh voln Releya i Lémba v tekhnike (Physical Foundations of the Application of Ultrasonic Rayleigh and Lamb Waves in Technology), Nauka, Moscow, 1966.

Translated by M. E. Alferieff
Edited by S. J. Amoretty