Supercritical velocities of domain walls in orthoferrites

M. V. Chetkin, A. I. Akhutkina, and A. N. Shalygin

Moscow State University

(Submitted 2 November 1978)
Pis'ma Zh. Eksp. Teor. Fiz. **28**, No. 11, 700–704 (5 December 1978)

Record high velocities of a domain wall were obtained in yttrium orthoferrite as high as 6×10^6 cm/sec, or three times larger than the critical velocity. Motion of a domain wall with superlimiting velocity reveals a nonstationary behavior that develops at a distance on the order of 0.5 cm.

PACS numbers: 75.60.Ch, 75.70.Kw, 75.50.Dd

The existence of a critical domain-wall velocity in ferromagnets was predicted theoretically by Walker.[1] Akhiezer and Borovik have shown that the velocity of the wave of rotation of the magnetic moment in ferromagnets in easy-plane antiferromagnets is limited by the phase velocity of the spin waves.[2] The question of the possibility of reaching this critical velocity was posed in Ref. 3 and remained debatable for a long time. The critical domain-wall velocity due to the mechanism indicated above was first observed in yttrium orthoferrite[4] and amounted to 2×10^6 cm/sec in pulsed magnetic fields of 700–900 Oe. It will be shown in the present paper that further increase of this field leads to an increase in the velocity of the domain wall to 6×10^6 cm/sec, and the motion at velocities above critical ceases to be laminar and becomes unstable. Investigations of the velocity of a single straight-line domain wall in an optically polished $YFeO_3$ plate perpendicular to the optical axis and measuring $6\times3\times0.7$ mm were performed by the procedure of Refs. 4 and 6. The gradient of the constant magnetic field perpendicular to the sample was 1500 Oe/cm and was directed along the *a* axis of the crystal. The velocity of the domain wall as a function of the pulsed magnetic field, $v(H_u)$, is shown in Fig. 1. This velocity was obtained by measuring the difference between the times at which the moving wall crossed two light spots separated by a distance of 750 μm. Similar results were obtained also at a distance 330 μm between the spots; this attests to uniformity of the motion of the walls over such distances. The minimum time necessary for the wall to negotiate a distance of 750 μm was 12 ± 0.5 nsec. At H_u less than 700 Oe, the results agree with the data of Refs. 4–6. In stronger fields, the velocity increases quite sharply, to 3.8×10^6 cm/sec and appears to have a limit in the magnetic field interval 950–990 Oe. This peculiarity takes place at a wall velocity equal to double the maximum spin–wave velocity $v_{sw} = \gamma(2H_eD)^{1/2}$ in the yttrium orthoferrite,[5,6] and attests to a strong nonlinearity of the investigated process. With further increase of the pulse field, the wall velocity increases to 6.0×10^6 cm/sec. The entire experimentally obtained $v(H_u)$ curve lies below the straight line corresponding to the mobility of this sample. The fact that the signals from the FÉU-30 photomultiplier did not decrease with time when the light spots were located at different points of the sample and the walls moved in one direction is evidence that the sample remained two-domain. Thus, the domain wall in $YFeO_3$ moves with a velocity three times larger than the minimum velocity of the spin waves. This result exceeds the scope of the known one-dimensional solutions and calls for a search for new possibly three-dimensional solutions. From the work of Slonczewski[7] and Schlomann[8] it follows that after the critical velocity is reached, be it the Walker critical limit or the limit due to the onset of Bloch lines in the moving wall, the velocity of the wall decreases with increasing magnetic field. It is seen from Fig. 1 that after the critical value is

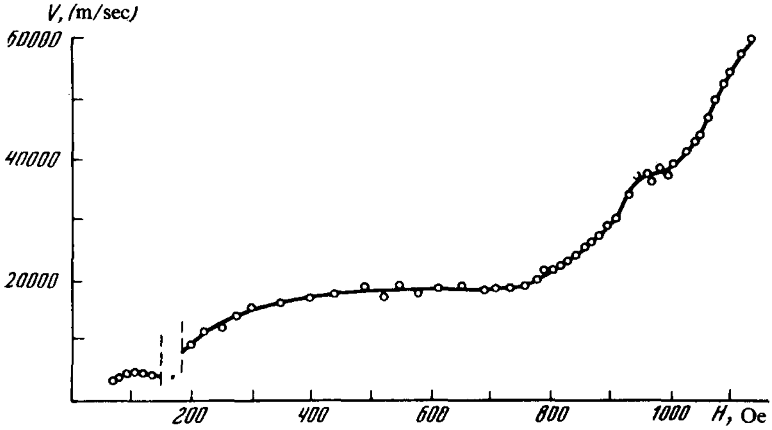

FIG. 1. Velocity of single domain wall in a $YFeO_3$ plate perpendicular to the optical axis, as a function of the amplitude of the pulsed magnetic field.

reached the velocity continues to increase strongly. Perturbations of the magnetic-soliton, which have a velocity exceeding the critical values and are even functions of $\xi = (x - vt)$,[9,10] cannot describe a wall that is describable by an odd function of ξ.

We have performed experiments aimed at checking on the stationary character of the wall motion. It was found that at a distance up to 1.5 mm, equal to the internal dimension of the coil that produced the magnetic field, there are no velocity instabilities in the entire interval of pulsed fields. On the trailing edge of the light pulses obtained when the light spot crossed the wall we observed a substantial instability, which takes place only in the case if in the initial section of the motion the velocities exceeded the critical value. Figure 2a shows an oscillogram of the photomultiplier current pulse produced during the forward and reverse motion of the domain wall

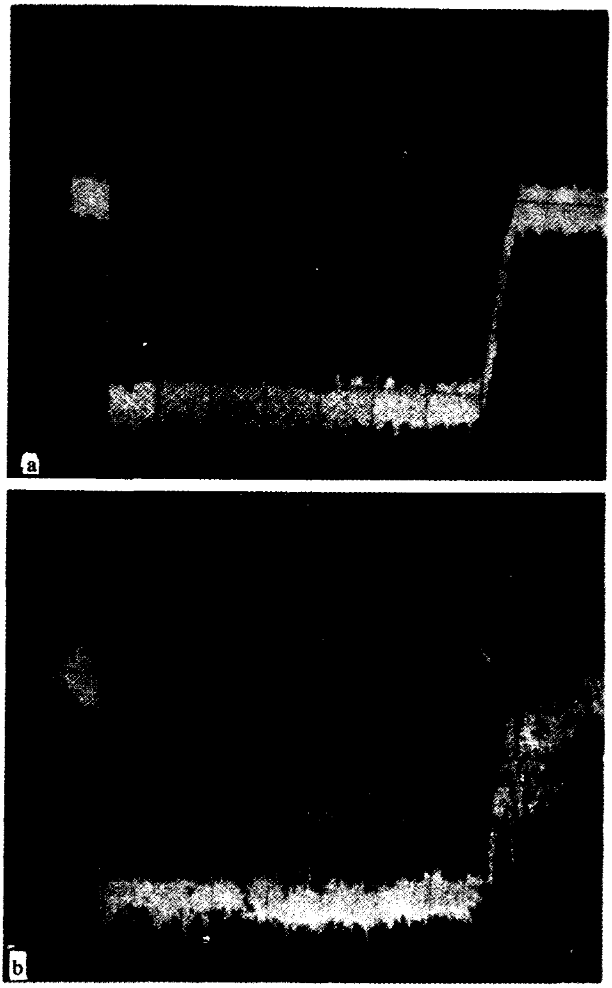

FIG. 2. Oscillograms of photomultiplier current pulses produced in the forward and reverse motion of the domain wall in the $YFeO_3$ sample when the wall crosses a light spot situated inside the coil that produces the pulse field. a) Wall velocity inside the coil less than the critical value, b) larger than the critical value.

crossing a light spot focused inside the coil that produces the pulsed field, for the case when the velocity within the limits of the coil was 1.8×10^6 cm/sec, i.e., below the critical limit. Figure 2b shows the same pulse when the velocity within the limits of the coil was 5×10^6 cm/sec. In this case one can see a strong instability of the travel time of the wall to its extreme position, determined as $(1/2)H_u/(dH/dx)$, and back. Similar instabilities appeared at all velocities exceeding the critical value. The distance at which the instability sets in is estimated at 0.5 cm, leading to a characteristic instability development time $\sim10^{-7}$ sec.

Thus, after going through the critical velocity, the wall motion becomes turbulent, and it is this which causes the instability of the wall motion observed at large travel distances. The solution of the problem of the motion of the domain wall must in this case be three-dimensional, just as on going through the limit of laminar flow of a liquid, when the velocity begins to increase exponentially.[11] The wall velocity is unstable also at velocities somewhat higher than the velocity of the transverse acoustic oscillations, as was observed in Refs. 12 and 5. It is possible that in this case, too, turbulent magnetoelastic waves are excited. The region of instability is quite narrow here because of the small constant of the magnetoelastic coupling; the characteristic dimension in which the instability develops is 0.05 cm, and its settling time is 10^{-7} sec. The scatter of the travel time in Fig. 2b amounts to 0.2 μsec, the total duration of the entire pulse is 2 μsec, and the duration of the control pulse is 1.5 μsec. Thus, the domain-wall velocity instability that develops over a distance on the order of 0.5 cm was quite large; the velocities at these distances differed by more than a factor of two. The instability of domain-wall motion could be investigated more accurately if the diameter of the coil that produces the controlling magnetic field were larger than the characteristic instability-settling distance.

From this point of view, interest attaches to low-temperature investigations, when the mobility of the domain walls of the orthoferrites, due to the four-magnon processes, increases strongly. It is of interest also to photograph in experiment domain walls moving with critical velocities by using picosecond lasers.

The authors are deeply grateful to I.E. Dzyaloshinskiĭ for a discussion of the results and for valuable remarks.

[1] R.L. Walker, in: I.F. Dillon, ed., Magnetism, III New York, 1963, p. 451.

[2] I.A. Akhiezer and A.E. Borovik, Zh. Eksp. Teor. Fiz. **52**, 1332 (1967) [Sov. Phys. JETP **25**, 885 (1967)].

[3] U. Enz, Helv. Phys. Acta **37**, 245 (1964).

[4] M.V. Chetkin, A.N. Shalygin, and A. de la Campa, Fiz. Tverd. Tela (Leningrad) **19**, 3470 (1977) [Sov. Phys. Solid State **19**, 2029 (1977)].

[5] M.V. Chetkin and A. de la Campa, Pis'ma Zh. Eksp. Teor. Fiz. **27**, 168 (1978) [JETP Lett. **27**, 157 (1978)].

[6] M.V. Chetkin, A.N. Shalygin, and A. de la Campa, Zh. Eksp. Teor. Fiz. **75**, 2346 (1978) [Sov. Phys. JETP **48**, No. 6 (1978)].

[7] I.C. Slonczewski, Internat. J. Magnetism **2**, 85 (1972); J. Appl. Phys. **45**, 2705 (1974).

[8] E. Schlömann, J. Appl. Phys. **47**, 1142 (1976).

[9] V.M. Eleonskiĭ, N.N. Kirova, and N.E. Kulagin, Zh. Eksp. Teor. Fiz. **74**, 1814 (1978) [Sov. Phys. JETP **47**, 946 (1978)].

[10] V.G. Bar'yakhtar, B.A. Ivanov, and A.L. Sukstanskiĭ, Fiz. Tverd. Tela (Leningrad) **20**, 2177 (1978) [Sov. Phys. Solid State **20**, 1257 (1978)].

[11] L.D. Landau and E.M. Lifshitz, Mekhanika sploshnykh sred (Mechanics of Continuous Media), Moscow, 1954, p. 129 [Pergamon, 1958].

[12] C.H. Tsang and R.C. White, AIP Conf. Proc. **29**, 552 (1976).