Supersonic domain-wall dynamics in yttrium orthoferrite

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The shape of a moving domain wall in yttrium orthoferrite depends strongly on the velocity and mobility of the wall. Supersonic motion of a domain wall becomes two-dimensional and time-varying.

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Previous study[1] of the dynamics of domain walls in orthoferrites, through measurements of the time required for the wall to traverse a given distance, has shown that at velocities above the transverse sound velocity there is a region of unstable motion. The measurement method used in Ref. 1 could not reveal the shape of the moving domain wall. The theory for the instability of the supersonic motion of a domain wall which has been worked out so far is one-dimensional.[2,3]

In the present experiments we studied the supersonic dynamics of domain walls in $YFeO_3$. At supersonic velocities the wall motion ceases to be one-dimensional. The deviation can be seen more clearly at a higher wall mobility, and in $YFeO_3$ it is seen best at 100 K, where the mobility is near its maximum. For high-speed photography we used 6-ns light flashes from the dye oxazine, itself illuminated with light pulses from an LGI-21 laser. The samples were 100 μm thick, cut perpendicular to the optic axis. The difference between the orientation angles of the polarization plane for two oppositely magnetized domains at the wavelength 0.63 μm was 58° (Ref. 4) and provided a very high contrast for the dynamic domain structure. It was thus possible to detect the "instantaneous" positions of a wall directly on high-speed photographic film, without using the electron-optical image converters which are customarily used to study the dynamics of domain walls in ferromagnets.[5,6] An isolated straight domain wall of an intermediate type was produced by a gradient magnetic field. This wall was moved by a pulsed field produced by two coils with an inside diameter of 1.5 mm. The rise time of the field pulse was 20 ns. At velocities up to 4000 m/s, which correspond to the transverse sound velocity, the moving wall remains strictly straight. As H is raised above 60 Oe, a deviation from one-dimensional motion becomes perceptible. The wall becomes curved as it moves, and semicircular formations appear on it. These are leading regions with a scale dimension of a few hundred microns; they are moving more rapidly than the straight parts of the wall. As they grow, the rectilinear part shrinks and ultimately disappears completely. Where two adjacent leading regions touch, the wall acquires a "singularity." Figures 1a-1c show a sequence of photographs of the "instantaneous" positions of a moving wall in a pulsed field $H = 140$ Oe, at intervals of 20 ns. In general, the positions of the leading regions on the wall are random, but they usually form relatively close to the coil turns, where the magnetic field is slightly higher than at the center.

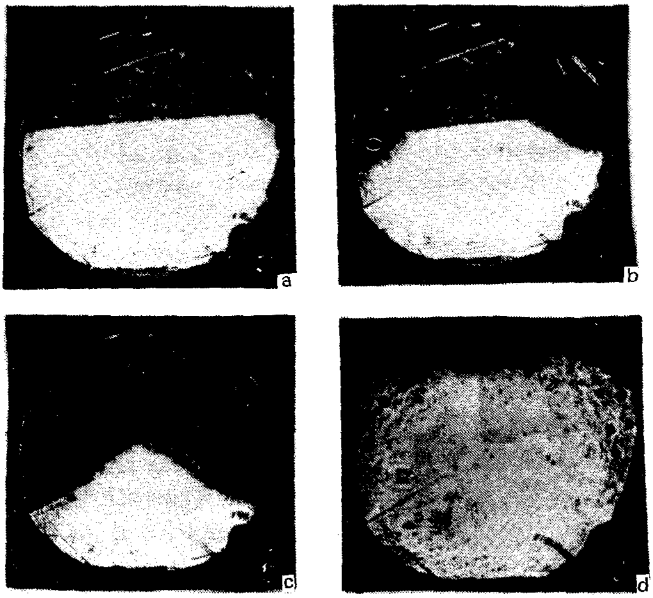

FIG. 1. Sequence of photographs, taken at 20-ns intervals, of the dynamic domain structure in $YFeO_3$ in a magnetic field of 140 Oe (a, b, c) or 2300 Oe (d).

Figure 2 shows the velocities of the straight regions and the velocities of the crests of the leading regions as functions of H. At $H > 25$ Oe the velocity of the straight region of a wall remains constant, equal to the transverse sound velocity (curve a). The crests of the leading regions move considerably faster (curve b). Figure 3 shows some representa-

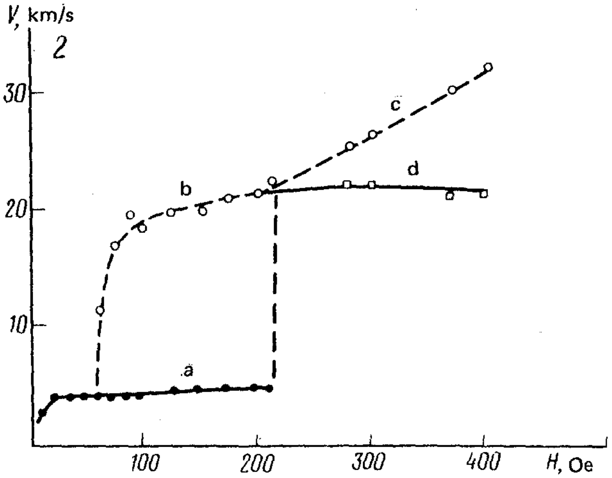

FIG. 2. Magnetic-field dependence of the velocity of the straight part of a domain wall in $YFeO_3$ (a), of the velocity of the crests of the leading regions (b and c), and of a domain wall after it has straightened out again (d).

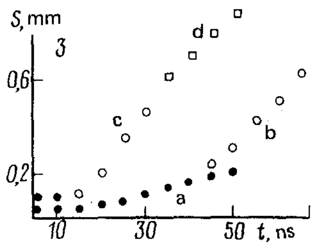

FIG. 3. Time dependence of the distances traversed by various parts of a domain wall, $S(t)$. a–Straight regions; b–crests of leading regions, at $H = 140$ Oe; c–crests of leading regions; d–domain wall after it has straightened out again, at $H = 375$ Oe.

tive results on $S(t)$, the dependence of the distance traversed by a straight wall and by the crests of the semicircular parts of a wall on the time (curves a and b, respectively). At $H = 200$ Oe the crests of the leading regions reach a limiting velocity.[1] As the pulsed magnetic field is raised further, the number of leading regions increases; the dimensions of these regions decrease (Fig. 1d); and the entire surface of the wall seems to be "boiling." Motion of this type continues for 10–15 ns (Fig. 2c), and then the wall straightens out and slows back down to the limiting velocity (Fig. 2d). Curves c and d in Fig. 3 show the dependence $S(t)$ for the crests of the leading regions and for a straightened wall, respectively, in a magnetic field of 375 Oe. The wall straightens out in the following manner: The straight parts of a wall adjacent to the "singularity" on the wall move at the limiting velocity normal to the wall (Fig. 1d). As a result, the velocity of the "singularity" increases, and the wall straightens out. During the light pulse the wall traverses a substantial distance. On some photographs we could see both the position of a straight wall and the position of a leading part of this wall, which appeared during the light pulse. The values found for the wall velocity when it exceeds the limiting velocity, found from a photometric study of these photographs, agree with the data shown in Fig. 2. Consequently, the supersonic and "superlimiting" motion of the domain walls in yttrium orthoferrite is two-dimensional and time-varying. The time variation of the wall motion and the deviation from a straight wall are very sensitive to the wall mobility μ. At $\mu = 5000$ cm/(s · Oe), the time variation of the motion and the deviation from a straight wall are nearly imperceptible. This conclusion corresponds to the results of Ref. 4. At $\mu = 20\,000$ cm/(s · Oe), the time variation and the large-scale, two-dimensional nature of the supersonic wall motion become very clearly defined. It should be noted that the theory, which has been worked out so far on the interaction of a moving domain wall with sound, treats only the one-dimensional motion of a wall and apparently needs refinement. The theoretical model of Ref. 7 for the "superlimiting" motion of domain walls was constructed under the assumption of a one-dimensional wall. As was shown above, the motion at the "superlimiting" velocity is not one-dimensional. This face must be incorporated in the theory. We do not rule out the possibility that the motion of domain walls at supersonic and superlimiting velocities is three-dimensional. In future experiments on the domain-wall dynamics in orthoferrites it will be necessary to use laser pulses in the subnanosecond and picosecond ranges.

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