Maximum velocity of a domain wall in a weak ferromagnet

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The velocity of a straight-line domain wall in orthoferrite plates perpendicular to the optical axis is investigated. It is shown that dependence of the velocity on the amplitude of the pulsed magnetic field ceases to be linear when the velocity of the domain wall becomes equal to the velocity of the transverse sound, and exhibits saturation at velocities 2×10^4 m/sec. This saturation of the velocity is attributed to excitation of spin waves in the weak ferromagnet by the moving wall. A generalization of the formula for the maximum of the domain wall in a ferromagnet is obtained for the case of weak ferromagnets. The value 1.7×10^4 m/sec obtained from this formula for the maximum velocity is in qualitative agreement with experiment.

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Interest in the dynamics of the motion of domain walls in ferromagnets has increased recently. Much attention is being paid to the velocity of cylindrical domains and domain walls in iron-garnet films, in view of their use in memory systems.[1] In this case, however, it becomes possible to obtain velocities on the order of several tens or hundreds of meters per second, much less than the Walker limit. The physical reason for the low velocities of the domain walls in iron garnets is the appearance of Bloch lines in the walls. Considerably higher domain-wall velocities are observed experimentally in orthoferrites

Thus, White,[2] using the Sixtus-Tonks method, obtained domain wall velocities 1.2×10^4 m/sec. Velocities 2.5×10^4 m/sec without visible saturation in strong fields were obtained by Konishi,[3] who used for their measurement the method of the collapse of the cylindrical magnetic domains. The motion of a strictly linear domain wall in orthoferrite $YFeO_3$ and $TmFeO_3$ plates perpendicular to the optical axis[4] makes it possible to determine its velocity[5] more accurately than in[2] and[3].At a gradient 500 Oe/cm along the *a* axis, a system of two very contrasty oppositely magnetized domains is produced in the plate (Fig. 1), with a strictly linear boundary perpendicular to the surface of the sample. This boundary, at a magnification of 1000, was observed in a crossed polarizer and analyzer. The electric field of the light wave incident on the orthoferrite plate was directed along the wall. The observed width of the wall was 2 μm (Fig. 2). This is considerably more than its actual width, which is estimated at 300 Å. The experimental dependence of the velocity of a strictly linear domain wall in $YFeO_3$ in a field gradient 500 Oe/cm, directed along the *a* axis, is shown in Fig. 3. The linear dependence of the velocity of the domain wall on the amplitude of the pulsed magnetic field is violated twice. First when the wall velocity is equal to the velocity of the transverse sound waves, and second at a wall velocity 2×10^4 m/sec. If the path of

FIG. 1. Domain structure in $YFeO_3$ plate perpendicular to the optical axis in a magnetic field with a gradient 500 Oe/cm directed along the a axis. Plate thickness 80 μm, magnification 30×.

the wall exceeds 500 μm in the field interval 155–845 Oe, instability of the velocity is observed.

The physical reason for the existence of large domain-wall velocities in orthoferrites was not clear before. It seems to us that the limit of 2×10^4 m/sec of the domain-wall velocity in orthoferrites is due to excitation of an optical mode of the spin wave. The simple Walker formula, which is valid for ferromagnets.

$$v = 2\pi\gamma M\sqrt{A/K}, \tag{1}$$

where M is the magnetization, A is the exchange constant, and K is the anisotropy constant, yields for orthoferrites a maximum velocity 10 m/sec. Allowance for the orthorhombic anisotropy of the orthoferrite, as in[6], leads to the expression

$$v = 2\pi\gamma\frac{q_2}{\sqrt{q_1}}, \tag{2}$$

for the maximum velocity of the wall, where $q_{1,2}=K_{1,2}/2\pi M^2$, for which we obtain for $YFeO_3$ a velocity limit of only 3.6×10^3 m/sec. Formula (1) can be modified to the form

$$v = \omega_{\text{res}}\sqrt{A/K}. \tag{3}$$

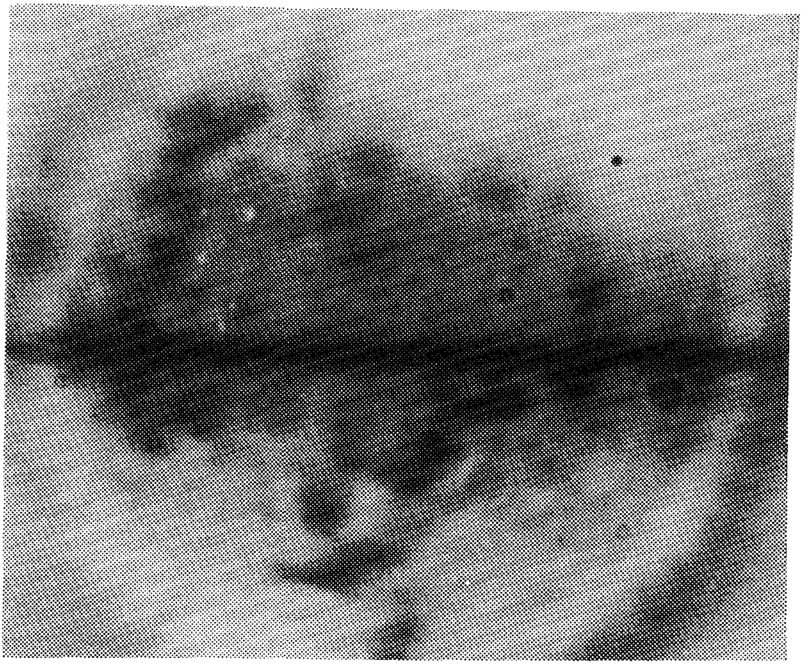

FIG. 2. Domain wall in $YFeO_3$ sample perpendicular to the optical axis and of thickness 80 μm, in a magnetic field with a gradiient 500 Oe/cm, in a polarizer crossed with an analyzer. Magnification 1000×.

The energy spectrum of a weak ferromagnet differs substantially from the energy spectrum of a ferromagnet for which formula (3) is strictly valid. In the case of an orthoferrite having a magnetic-sublattice canting angle 0.008 rad, it is necessary to replace ω_{res} in (3), by way of estimate, with the quantity

$$\omega_{\text{res}} = \gamma \sqrt{2H_E H_A}, \tag{4}$$

where H_E and H_A are the exchange and anistropy fields. We then have for the maximum velocity

$$v = \sqrt{2H_E D} \tag{5}$$

where $d = 2A/I_0$, so that we get for $YFeO_3$ the value $v = 1.7 \times 10^4$ m/sec, which is quite close to the experimentally obtained 2×10^4 m/sec.

The zero-gap branch of the spin waves in orthoferrites does not limit the wall velocity. By virtue of the large wall mobility (6000 cm/sec-Oe), the Walker limit 1000 cm/sec is reached in fields 0.2 Oe, when uniform motion of the wall is impossible because of the coercivity of the sample. In the case of an orthoferrite, the situation is exactly the same as in a ferromagnet. The velocity limit sets in when the wall velocity

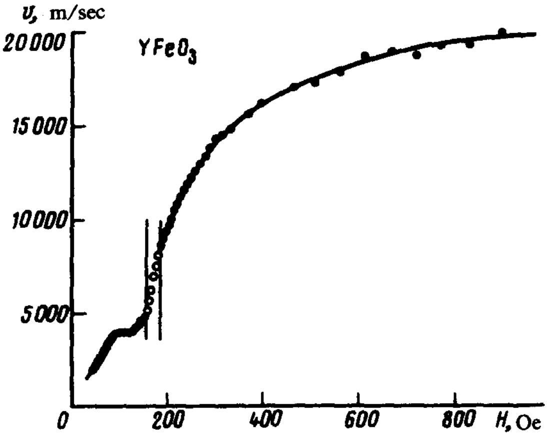

FIG. 3. Velocity of domain wall in $YFeO_3$ 80 μm thick as a function of the amplitude of the pulsed magnetic field.

becomes equal to the spin-wave velocity on the "tail" of the domain wall, where the linear theory of spin waves is valid. This situation was considered by Schlömann[7] for a ferromagnet, and an expression for the Walker velocity was obtained from the dispersion relation for the spin waves. From the dispersion law $\omega^2=\gamma^2[2H_E(H_k+DK^2)]$ follows Eq. (5) for large K. A similar analysis can be carried out for weak ferromagnets. By investigating the limiting velocity of the domain walls in weak ferromagnets, we can determine the anisotropy of the spin-wave velocity. It follows from (3) and (4) that the limiting velocity of domain walls in orthoferrites should not depend on the temperature, whereas according to (2) this dependence should be appreciable in rare-earth orthoferrites in which K_1 depends on the temperature.

Thus, the largest-domain wall velocity in magnetically ordered substances should be expected in weak ferromagnets with strong exchange interaction, where the spin-wave velocities and the domain-wall mobilities are maximal.

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