Ultrafast magnetic-moment-flip waves in iron garnet films

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Pis'ma Zh. Eksp. Teor. Fiz. **35**, No. 1, 22–25 (5 January 1982)

Record high velocities, up to $\sim 6\times 10^4$ m/s, have been observed for magnetic-moment-flip waves in iron garnet films. These velocities are more than an order of magnitude higher than the minimum spin-wave phase velocity. The velocities of the domain walls do not exceed the Walker limit in pulsed fields up to the effective uniaxial-anisotropy field.

PACS numbers: 75.70.Kw, 75.30.Ds, 75.50.Gg

The dynamics of domain structures in magnetically ordered media has recently come under intense study. The domain-wall velocities in iron garnet films are usually[1] no higher than ~ 100 m/s, while they reach 1.4×10^3 m/s in samples with an orthorhombic anisotropy.[2] Significantly higher domain-wall velocities have been observed experimentally in orthoferrites by Chetkin *et al.*,[3,4] who have reported values up to 6×10^4 m/s in pulsed magnetic fields H_p up to 3 kOe (Ref. 5). A theory derived by Walker[6] predicts a maximum velocity for domain walls in ferromagnetics. Akhiezer and Borovik[7] have shown that the velocity of a magnetic-moment flip wave in a ferromagnet is limited by spin-wave phase velocity v_φ. Eleonskiĭ *et al.*[8] have derived an analytic expression for v_φ for materials exhibiting an easy-axis anisotropy, and this expression applies to iron garnet films. In these studies as well as in others (Refs. 9 and 10, for example), the dynamics of domain structures in magnetically ordered media with an easy-axis anisotropy has been studied theoretically and experimentally only for magnetic field H between 0 and H_u, where H_u is the effective uniaxial-anisotropy field.

In this letter we are reporting some new experimental results on the dynamics of the magnetization reversal of iron garnet films in fields $H_p \gtrsim H_u$, obtained by high-speed photography.[11] The sample was illuminated by luminescence excited by pulses from an LGI-21 laser, ~ 8 ns long, in an optical cell containing a rhodamine 6G dye solution. A UM-93 image converter was used to raise the image brightness. The samples were iron garnet films grown by liquid-phase epitaxy on the (111) plane of $Gd_3Ga_5O_{12}$ substrates. The particular results we are reporting here correspond to a sample with the composition $(BiTm)_3(FeGa)_5O_{12}$ with a thickness $h\cong 10 \mu$m, a collapse field $H_0\cong 107$ Oe, and $H_u\cong 1000$ Oe. The pulsed field was produced by a single-layer plane coil with an inside diameter $d = 1.3$ mm. The field at the center of the coil, H_p $(r=0)$, where r is the distance from the center of the coil, was varied from 0 to 4000 Oe in these experiments. The rise time of the H_p pulse did not exceed 35 ns. The sample was initially in a constant bias field H_b; then a pulsed field antiparallel to H_b was applied, and the dynamics of the magnetization reversal was studied at various times τ, reckoned from the middle of the leading edge of H_p (Fig. 1).

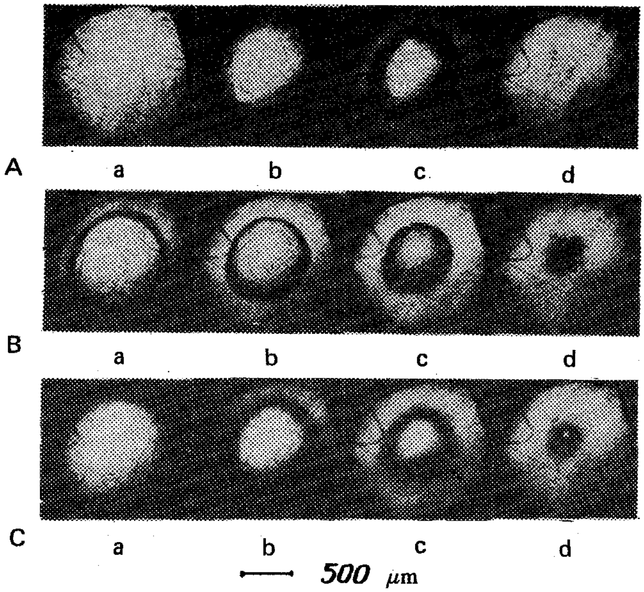

FIG. 1. Dynamics of the magnetization reversal of the part of the iron garnet film bounded by the plane coil. $H_b = 86$ Oe. A: $\Delta H(0) = 520$ Oe. a—$\tau = 0$; b—60; c—150; d—400 ns. B: $\Delta H(0) = 1000$ Oe. a—$\tau = 40$; b—80; c—120; d—200 ns. C: $\Delta H(0) = 2000$ Oe. a—$\tau = 15$; b—20; c—25; d—35 ns.

It can be seen from Fig. 1A that at the central part of the coil, where $\Delta H(r) = H_p(r) - H_b < H_u$, the magnetization reversal results from the motion of domain walls, while near the coil, where $\Delta H(r \sim d/2) > H_u$, the magnetization reversal begins through an inhomogeneous rotation of the magnetization vector. After beginning near the coil turns, where $\Delta H(r \sim d/2)$ is at its maximum, this reversal rapidly propagates into the region of weaker fields, $\Delta H(r \to 0)$, exciting a magnetic-moment-flip wave, which propagates from the edges of the coil toward its center. To study the motion of this wave, we carried out experiments in nearly crossed polarizers, so that the magnetic-moment-flip wave could be visualized as a dark ring (Fig. 1).

It follows from Fig. 1A that in the case $\Delta H(0) < H_u$ the magnetization reversal through the inhomogeneous rotation of the magnetization vector occurs over the entire area bounded by the coil, except in a certain strictly oriented triangular region at the center of the coil, where the magnetization reversal results from the motion of domain walls (*d* in Fig. 1A). For convenience, we will refer to this region as a "triangular magnetic domain." The experimental results reveal that there is a certain field interval $\Delta H(0) < H_u$ in which, regardless of the position of the sample with respect to the coil and regardless of the orientation of H_b and H_p, there are always strictly oriented triangular magnetic domains. If the condition $H_b < H_0$ holds in the initial state, the triangular magnetic domain is compressed by the pulsed field H_p, and a broadening of the magnetic domains is observed within the triangular domain (Fig. 1A). If instead $H_b > H_0$, only a contraction of the triangular domain is observed. The experiments show that the orientation of the triangular domain is strictly determined by the directions of the anisotropy easy axes in the plane of the film.

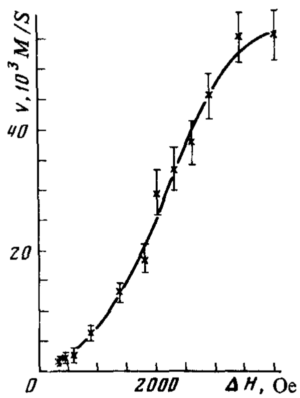

FIG. 2. Dependence of the velocity of the magnetic-moment-flip wave on the magnetic field $\Delta H(0)$.

In fields $\Delta H(0) > H_u$ the magnetization reversal due to the magnetic-moment-flip wave occurs over the entire area of the sample bounded by the coil (Figs. 1B and 1C). From the time dependence of the distance travelled by the magnetic-moment-flip wave we determined the velocity v_{MMFW} for various values of $\Delta H(0)$. Figure 2 is a plot of v_{MMFW} against $\Delta H(0)$. From the equation in Ref. 8 we estimate the minimum spin-wave phase velocity in this sample to be $v_\varphi \cong 3\times 10^3$ m/s, in approximate agreement with the minimum velocity of a magnetic-moment flip wave, $v_{MMFW} \cong 2\times 10^3$ m/s. It follows from Fig. 2 that v_φ is by no means the maximum velocity for the magnetic-moment-flip wave; at magnetic fields $\Delta H(0) \sim 4$ kOe, this wave propagates at a velocity more than an order of magnitude higher than v_φ.

In its initial state, the sample exhibits a stripe domain structure (Fig. 1). The velocities of the domain walls were determined from the time dependence of the width of the stripe domains. It can be seen from Figs. 1B and 1C that in strong pulsed fields the initial stripe domains do not manage to expand even slightly during the motion of the magnetic-moment flip waves. Analysis shows that in fields $H_p \lesssim H_u$, and even above H_u, the velocity of the domain walls reaches saturation at ~ 100 m/s; the value does not exceed the Walker limit, which is ~ 110 m/s for this sample. The results thus show that in these particular iron garnet films there is no significant increase in the domain-wall velocity in strong pulsed fields, as there is in orthoferrites.[3–5] We wish to emphasize that in fields $H_p \gtrsim H_u$ we do not observe a growth of nucleation centers with the magnetization opposite H_b, since the magnetization reversal, which results from the inhomogeneous rotation of the magnetization vector, is far more rapid than the growth of these nucleation centers.

We are deeply indebted to M. V. Chetkin for a discussion of these results and for useful comments.

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Translated by Dave Parsons
Edited by S. J. Amoretty