Magnetic vortices in ferrite-garnet films

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The excitation of magnetic vortices during pulsed magnetic reversal of ferrite-garnet films from the saturated state with limiting low dissipation under the action of a spatially inhomogeneous, axially symmetrical field has been observed experimentally for the first time. The investigations were performed by the method of high-speed photography. The magnetic vortices are interpreted as Rossby solitons.

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Magnetic solitons can form in uniaxial ferromagnets and are most likely to be seen when the dissipation is extremely low.[1,2] Magnetic disturbances generated by the domain wall during motion and prior to it, which are interpreted as magnetic solitons, were observed experimentally by Ivanov *et al.*[3] However, the most likely reason for the formation of such disturbances is local nucleation.[4]

In this work, we attempted to observe experimentally the formation of magnetic solitons during pulsed magnetic reversal from the saturated state[4–6] of ferrite garnet films which have extremely low damping and which have the composition $(YLuBi)_3(FeGa)_5O_{12}$. The films were grown by the method of liquid-phase epitaxy on a $Gd_3Ga_5O_{12}$ substrate with (111) orientation from a solution in a melt not containing PbO. The pulsed magnetic field H_p, which was produced, just as in Refs. 3–7, by a flat coil with an inside diameter of about 1.5 mm, situated at the surface of the specimen, was an axially symmetrical magnetic field. Its maximum amplitude at the center of the coil (up to 3000 Oe) was higher than the uniaxial anisotropy field in the specimens investigated. The duration of the leading edge of the pulse did not exceed 25 ns. In the starting state, the specimen was magnetized up to the saturation field H_b, applied along the normal to its surface, while a field H_p was applied in the opposite direction. In this paper, we present data for a specimen with the following parameters: thickness, 32 μm; saturation magnetization 134 G; anisotropy field, 2300 Oe; gyromagnetic ratio

$\gamma = 1.77 \times 10^7$ Oe$^{-1}\cdot$s^{-1}, and, Gibert's dimensionless damping parameter, 0.009. We performed the investigations using the method of high-speed photography.[4,6] The duration of the illumination pulse was 8 ns.

Magnetization reversal begins during the action of the leading edge of the pulse H_p with rotation of the magnetization vectors near the loops of the coil, where the pulsed field is highest; the angle of rotation of these vectors is 180°.

In this case, a magnetic moment flip wave (MMFW), which moves from the periphery to the center, is formed; the velocity of the MMFW increases with H_p. Its maximum value, measured in the experiment, reached 60 km/s. The motion of MMFW reflects the spatial displacement of the boundary on which the intensity of the inhomogeneous field reaches a critical value with increasing pulsed field. This boundary separates the regions where rotation of magnetization does and does not occur. It is evident that with a fixed duration of the leading edge of the field pulse, the higher its amplitude, the more rapidly the intensity of the field reaches at a given point the cirtical value and the higher the velocity of MMFW.

At the end of the first magnetization reversal stage, approximately 10–20 ns after field pulse is applied, a region in which a magnetization reversal has not occurred remains at the center of the coil, which, due to the small cubic anisotropy, has a circular rather than a triangular shape, as in Ref. 7.

Later, the magnetization reversal process becomes fundamentally different in nature. Although the region in which the magnetization is not reversed continues to be compressed, inside it, the homogeneous state of the magnetization breaks down, leading to the formation of magnetic vortices. Figure 1 shows a typical image of such a vortex, obtained with "phase contrast" (crossed polarizer and analyzer). In the light-colored regions, the magnetization vectors are oriented along the normal to the plane of the film, while in the dark regions, they tilt away from it. The magnetic vortex, as a rule, is repeated exactly from pulse to pulse. Analysis shows that the streams of mag-

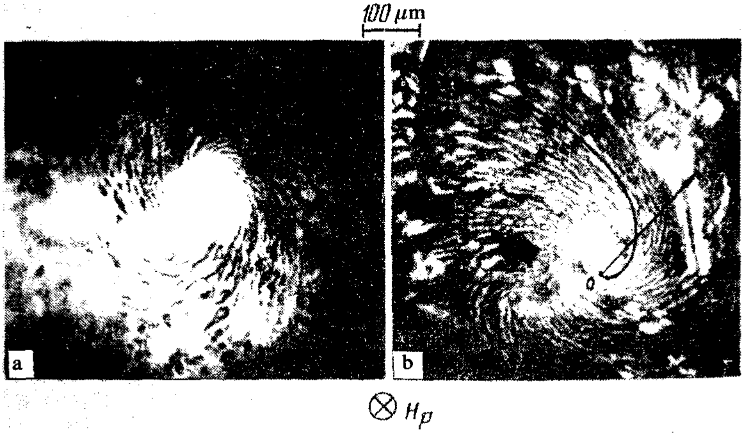

FIG. 1. Photograph of magnetic vortex 15 nsec after the application of a field pulse with $H_p = 1500$ Oe (at the center of the coil) and $H_b = 92$ Oe (Fig. 1a) and 50 ns after termination of the pulse (Fig. 1b).

netization in this vortex form a logarithmic spiral. When the orientations of the fields H_b and H_p are reversed, the direction of twisting of the spirals is also reversed. At a sufficiently high value of H_p, at the end of the magnetization reversal process, approximately 100 ns after the field pulse is applied, the magnetic vortex contracts into a small region which then collapses. A magnetic vortex also forms at the end of the magnetization reversal pulse, and the twisting of the spiral is reversed, from left (Fig. 1a) to right (Fig. 1b), relative to the direction of the field H_p. The vortex, which is formed at the end of the field pulse, is more distinct (Fig. 1b), so that it was used to establish the shape of the spiral. Analysis showed that the magnetization streams in the vortex form a logarithmic spiral. For comparison, Fig. 1b shows the curve $r = r_0 \exp(k\phi)$ where $r_0 = 90\,\mu$m, and $k = \mathrm{ctg}\alpha$, $\alpha = 43°$. The possible error in α, which amounts to ± 5°, is attributable to the fact that the pole of the spiral is not determined uniquely.

The observed magnetic vortices can be interpreted as Rossby solitons, typical examples of which are waves in the ocean and drift waves in a plasma.[8] The trajectories of particles in the ocean, which transport the Rossby waves are twisted by the Coriolis force, while trajectories of charged particles in a plasma are twisted by the Lorentz force. Twisting accompanying the motion of magnetic moments occurs in approximately the same manner, in accordance with the Landau-Lifshitz equation (excluding dissipation)

$$\partial \mathbf{M}/\partial t = -\gamma[\mathbf{M}, \mathbf{H}],$$

where M is the magnetization, and H is the external field, Rossby waves arise due to the spatial gradient of the Coriolis force and due to the hydrostatic pressure; drift waves arise due to the presence of a pressure gradient in the plasma, and magnetic vortices arise due to the gradient in the external field. All three types of waves propagate around the field-aligned axis of the system perpendicular to this gradient. Thus the analogy between these three types of waves is reasonably complete.

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