Spiral domains in single-crystal iron garnet films in static magnetic fields

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Spiral domains have been observed in magnetically uniaxial iron garnet films in static magnetic fields. The processes by which these domains arise, their restructuring, and their interaction in an external magnetic field have been studied. Whether these domains appear depends on the physical properties of the films and on the presence of certain special defects.

The domain structures which occur in single-crystal magnetic films with an easy-axis magnetic anisotropy are quite diverse, because of both the physical properties of the material itself and the effects of external magnetic fields and the temperature.[1] Recent additions to the classification of domain structures in uniaxial magnetic films are spiral domains, which can be formed, according to the results of recent studies,[2,3] by the application of bipolar[2] and unipolar[3] pulsed magnetic fields of a certain frequency and amplitude. In the present study, spiral domains have been formed by applying a static magnetic field of a certain strength along the direction perpendicular to the plane of the film. The range of conditions under which spiral domains can be formed has thus been broadened, but now a different approach must be used to explain the process.

We studied single-crystal iron garnet films of the system $(YBiSm)_3(Fe, Ga)_5O_{12}$, grown by liquid-phase epitaxy on $Gd_3Ga_5O_{12}$ substrates in the (111) orientation, with a thickness no less than 5 μm. The easy-magnetization axis ran perpendicular to the plane of the film. The domain structures which formed in various stages were observed by means of the Faraday effect. The external magnetic field of the desired strength was directed normal to the film.

The initial domain structure was the usual labyrinthal structure (Fig. 1a) characteristic of iron garnet films with a perpendicular anisotropy, with a period $2d = 4$–6 μm. A field $H_s = 85$ Oe causes complete magnetization reversal. When a static magnetic field is imposed along the direction perpendicular to the plane of the film, the domain structure changes. There are not only a broadening of the domains whose magnetization is along the field but also a movement of these domains. In a field $H = 45$ Oe (Fig. 1b), this restructuring of the domain pattern gives rise to a spiral whose turns consist of "crimped" dark domains. A further increase in the field straightens out the crimping and give rise to a more clearly defined spiral, in which there are 13 turns at a field $H = 48$ Oe. An increase in the field to $H = 55$ Oe is accompanied by an improvement in the quality of the spiral, a detachment of the spiral from the labyrinthal domain structure surrounding it, a progressive collapse of the turns of the spiral (starting at the periphery), and the formation of a bright region

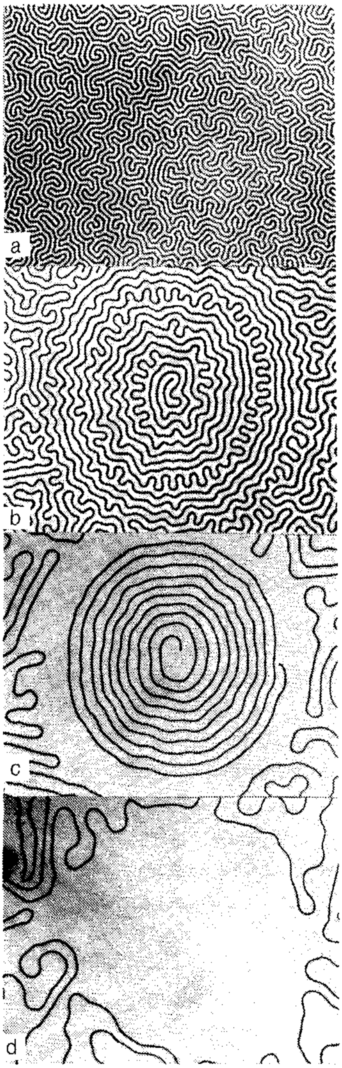

FIG. 1. Transformation of the domain structure with increasing magnetic field H: a—0 Oe; b—45 Oe; c—55 Oe; d—63 Oe.

between the spiral and the labyrinthal domains (Fig. 1c). The spiral, being relatively more sensitive to the external magnetic field, disappears completely, untwisting in the direction of the point at which the first inner turn is pinned at $H = 63$ Oe. The labyrinthal domains surrounding the spiral do not disappear until $H = 95$ Oe.

As the external magnetic field is reduced, the spiral domains in a film which has undergone complete magnetization reversal are first nucleated in a field $H = 56$ Oe and then develop (Fig. 2a). A very slight further reduction of the field leads to a rapid increase in the number of turns in the spirals and to the filling of the rest of the space in the film with labyrinthal domains (Fig. 2b). These domains shrink markedly; the spirals become deformed (Fig. 2c) and revert to their original state (Fig. 1a). The

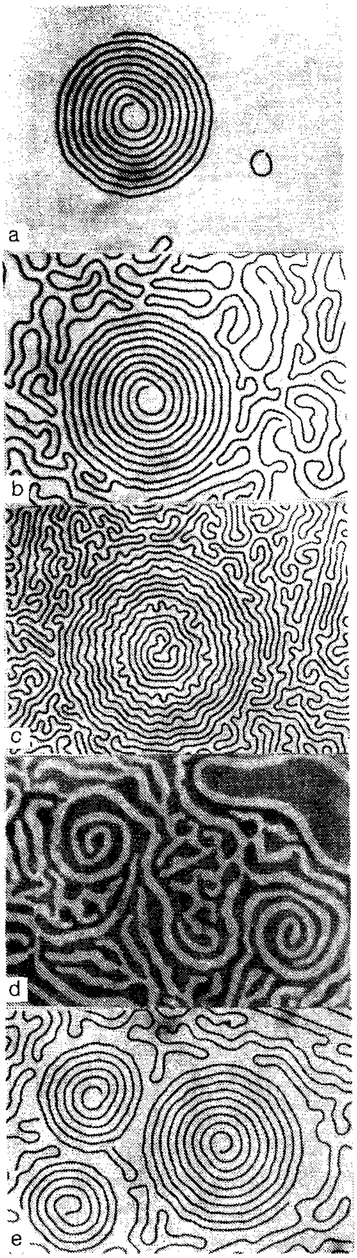

FIG. 2. *a*, *b*, *c*—Appearance and transformation of a spiral domain with decreasing strength of the magnetic field H [*a*—56 Oe; *b*—51 Oe; *c*—47 Oe]; *d*—domain structure in films of the composition $(YCa)_3(FeCoGe)_5O_{12}$; *e*—group of spiral domains.

observations show that the nucleation center of the spiral domains is often a defect (Fig. 1d), but the nature of this defect has not yet been established.

Again in the particular system of iron garnet films studied here, the spiral domains are thus stable static formations in an external magnetic field of a certain strength. These domains can be classified as regular domain structures along with labyrinthal domains, stripe domains, and magnetic bubbles (cylindrical magnetic domains). The nature of these domains depends on the physics of the material itself. Support for this assertion comes from the domain structure which contains a spiral domain of the opposite chirality, which has been observed in $(YCa)_3(FeCoGe)_5O_{12}$ films in a field $H=0$ (Fig. 2d).

The films in which spiral domains can exist at $H=0$ do not have a preferred direction for the orientation of domain walls, as can be seen from the essentially perfect isotropy of the specific energy of these walls.

During the application of a static magnetic field to film samples, a large number of spirals may arise simultaneously, having the same chirality but differing in the number of turns. It can been seen from Fig. 2b that there are seven spiral domains in the area corresponding to the field of view of the microscope (at a magnification of 60×). No significant shape changes or deformation of the spirals as a result of their relative positions were observed.

On the basis of the experimental data found on the spiral domains which arise in dynamic[2,3] and static magnetic fields, we can say that these domains constitute regular domain structures of a new type. Determining how they arise and exist will require further research on both the physical properties of the films themselves and the properties of the domains during various stages of the formation of the spirals.

[1]A. P. Malozemoff and J. C. Slonczewski, *Magnetic Domain Walls in Bubble Materials*, Academic Press, Orlando, 1979.
[2]G. S. Kandaurova and A. É, Sviderskiĭ, Pis'ma Zh. Eksp. Teor. Fiz. **47**, 410 (1988) [JETP Lett. **47**, 490 (1988)].
[3]F. V. Lisovskiĭ and E. G. Mansvetova, Fiz. Tverd. Tela (Leningrad) **31**, 273 (1989) [Sov. Phys. Solid State **31**, 876 (1989)].

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