Self-organization of the magnetic moment during pulsation oscillations and dynamic clustering or drift of 2D arrays of domains in thin films

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A self-organization of the distribution of the magnetic moment due to pulsation oscillations, due to a dynamic clustering, or due to a drift of 2D arrays of magnetic bubbles has been observed in iron garnet films. The formation of arrays from single or paired annular domains (the symmetry groups P6mm and Cmm2) has been observed. The formation of arrays from *L*- or *S*-shaped domains (group P2) and from alternating rows of dumbell-shaped domains of various sizes (group Pmm2) has also been observed.

We have previously reported[1–4] the observation and study of some new types of self-organization of the magnetic moment in some iron garnet films. The films had a large uniaxial anisotropy constant β_u. The effects occurred upon the application of unipolar magnetization pulses in a process involving the formation of arrays of dumbbell-shaped magnetic bubbles or of both dumbbell-shaped and circular magnetic bubbles, whose symmetry under static conditions corresponded to the space groups Pab2 and P6 and under dynamic conditions to the groups Cmm2 and P6mm. It was suggested[3] that by varying the parameters of the external agent and by using films with a non-uniaxial anisotropy one could produce some 2D arrays of domains of various shapes with quite diverse symmetry types. In this letter we are reporting some experiments which support this hypothesis.

In a first series of experiments we used an iron garnet film with the composition $(YGdYbBi)_3(FeAl)_5O_{12}$, with a thickness $t \approx 20\ \mu m$, on a $Gd_3Ga_5O_{12}$ substrate in the (111) orientation. The period of the labyrinthine domain structure in this film was $d = 58\ \mu m$, the uniaxial anisotropy constant was $\beta_u \simeq 20$, the magnetization was M $\simeq 7.7$ G, and the bubble collapse field was $H_c = 39$ Oe. Unipolar magnetic field pulses with an amplitude $\tilde{H} \simeq 75$ Oe, a length $\tau_p \simeq 2\ \mu s$, and a repetition period $T_r \simeq 1$ ms were applied to the film by a plane coil with an inside diameter of 1 mm. The magnetic field pulses were directed along the normal to the film surface, **n**. These pulses were triangular; i.e., the rise time τ_r and the fall time τ_f were about 1 μs.

Under the conditions described above, a structure as shown by the photograph(1) in Fig. 1a, formed from the original labyrinthine domain structure after about 100 magnetic field pulses. The symmetry of this domain structure is described by the 2D space group Pmm2. The corresponding Bravais cell with the pattern-forming elements is shown at the left in Fig. 2a. Each magnetic field pulse converts short domains into long ones, and vice versa, so that under dynamic conditions, with an averaging over many pulses, we observe a domain structure with the Bravais cell shown at the right

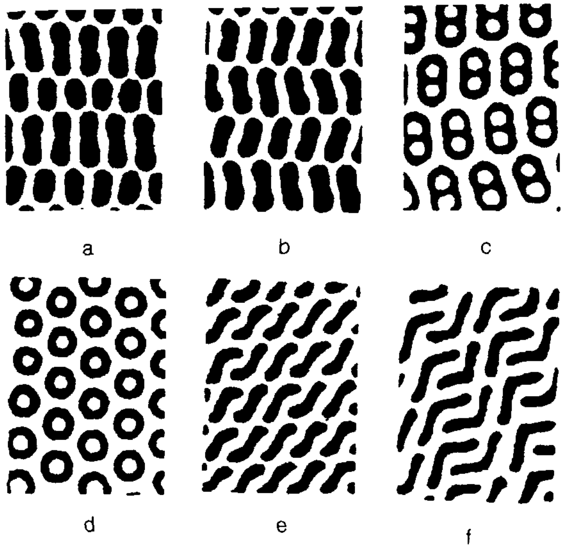

FIG. 1. Photographs of domain structures which arise in the course of self-organization.

in Fig. 2a (space group Cmm2). With a slight modification of the shape of the pulse, it is possible to produce, in the same film, a domain structure as shown in the photograph in Fig. 1b (symmetry group Pab2) and also Bravais cells for the static and dynamic regimes, as shown in Fig. 2b (the dynamic regime corresponds to the group

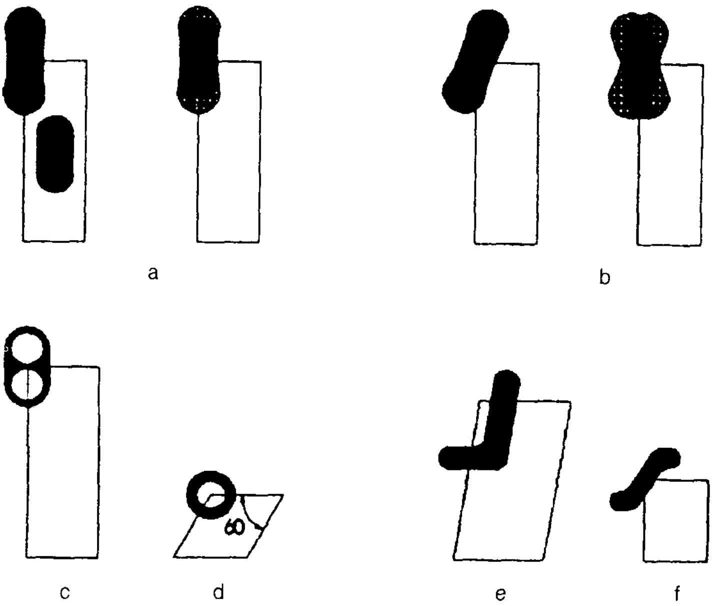

FIG. 2. Bravais lattices with pattern-forming elements: the prototypes for the domain structures in Fig. 1.

Cmm2). As in Refs. 1–3, the reorientation of the major axes of the dumbbell-shaped domains (under the influence of each magnetic field pulse) occurs not through a rotation of these domains but through the shock excitation of a pulsation mode of vibrations. In other words, the domains initially undergo a contraction, while retaining their original orientation of symmetry axes, to the point that they become nearly circular. They then expand along new symmetry axes. In contrast with the self-organization described in Refs. 1–3, in which case the reorientation of the major axes of the domains occurred through an angle of $\pi/2$, the angle in this case is about $\pi/6$.

A second series of experiments was carried out on a $(YBi)_3(FeGa)_5O_{12}$ film [(111) orientation, $t \approx 7$ μm, $d=60$ μm, $\beta_u \simeq 60$, $M \simeq 6.7$ G, $H_c = 14$ Oe]. We used a sinusoidal magnetic field with an amplitude $\tilde{H} > H_c$ and a frequency $f \sim 10^4$ Hz. In a certain interval of magnetic field amplitudes, a unipolar hexagonal array of circular magnetic bubbles formed from the original labyrinthine domain structure in the film. The direction of the vector **M** was the same in all these bubbles; i.e., there was a spontaneous symmetry breaking.[2)] As the amplitude $\tilde{H}$ was increased, however, the broken symmetry element was restored via a random nucleation and growth of clusters consisting of regions of the hexagonal array of magnetic bubbles with an antiparallel direction of the vector **M** in their interior[3)] ("antiparallel" with respect to the original array). The number of bubbles in these clusters, n_d, at the time at which the latter formed could be quite large. If a weak static magnetic field $H_0 \ll H_c$ was applied to the film in this situation and then progressively strengthened, there would be a rapid dissociation of the clusters (the symmetry would be broken again), and n_d would decrease. Simultaneously, there would be a displacement of fragments of the original array of magnetic bubbles. The tendency toward an ordering of clusters is first seen at $n_d \leqslant 6$, but a complete self-organization of the array of clusters, manifested in the formation of an ordered array of paired annular bubbles, is observed at $n_d = 2$ (Fig. 1c). The symmetry of the domain structure is described by the group Cmm2; the corresponding Bravais cell is shown in Fig. 2c. At a slightly stronger magnetizing field H_0, the clusters with $n_d = 2$ dissociate, and a hexagonal array of magnetic bubbles with a P6mm symmetry forms[4)] (Figs. 1d and 2d).

In a third group of experiments we used a $(LuBi)_3(FeGa)_5O_{12}$ film grown on a $Gd_3Ga_5O_{12}$ substrate in the (210) orientation. This configuration resulted in the formation of a pronounced rhombic component of the induced anisotropy ($\beta_p \sim \beta_u$, where β_p is the constant of the rhombic anisotropy). This film had $t = 14$ μm, $d = 14$ μm, $\beta_u = 3.3$, $M = 7.3$ G, and $H_c = 66$ Oe. When square unipolar pulses of a magnetic field with a length $\tau_p \sim 10$ μs, a repetition period $T_r = 10$ ms, and an amplitude $\tilde{H} > 90$ Oe were applied to this film, the original banded domain structure broke up, and the array began to drift as a whole. In the course of this drift, there was a self-organization accompanied by the formation of ordered arrays of S- or L-shaped domains (Fig. 1, e and f) with a symmetry described by the group P2. The Bravais cells are as shown in Fig. 2, e and f. The elements of the arrays acquire a chirality because of gyroscopic forces at the ends of the domains in the course of the drift.[6] This interpretation is supported by the circumstance that the twisting direction changed when the sign of the pulsed magnetic field was changed.

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1) The photographs of the domain structures were prepared for printing on an IBM PC-AT/386 computer with the Photo-Paint program of the CorelDRAW graphics package. The photographs were taken of "frozen" domain structures, i.e., in the absence of a magnetic field pulse.

2) In the original labyrinthine domain structure, the two possible directions of the magnetization vector, $\mathbf{M}\uparrow\uparrow\mathbf{n}$ and $\mathbf{M}\downarrow\uparrow\mathbf{n}$, are equivalent.

3) O'Dell[5] has observed and described a similar effect during a pulsed magnetization reversal of the films. The effect was called a topological switching of the polarity of an array of magnetic bubbles.

4) A self-organization of the domain structure in the second series of experiments was observed only when there was a small gap between the film and the coil which generated the alternating magnetic field; i.e., the alternating field had a radial component.

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