The excited state and dynamic spiral domain structure in a magnetic crystal

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A peculiar excited state and formation of dynamical macroscopic structures in the form of helical magnetic domains were observed visually for the first time in a polydomain uniaxial magnetic film crystal under suitable conditions of external pumping.

The behavior of the labyrinthine domain structure in uniaxial magnetic crystals in alternating fields in the frequency range 10^2–10^3 Hz has virtually been ignored. There are, at any rate, no experimental data which would indicate that an excited state with a stable dynamic domain structure, which differs qualitatively from a static domain structure, can occur as a result of a low-frequency pumping.

In this letter we are reporting the results of an experimental study of an epitaxially grown single-crystal garnet ferrite film $(Y, Sm)_3(FeGa)_5O_{12}$. The sample is a disk 5 mm in diameter. The easy-magnetization axis is directed perpendicular to the sample's plane. The domain structure is determined by means of the magneto-optical Faraday effect and the magnetic field is oriented along the normal to the sample.

In the initial state the film has an ordinary labyrinthine domain structure (Fig. 1a). The magnetization in the dark domains is directed toward the viewer and the magnetization in the light domains is directed away from the viewer. The domain-structure period ($2d$) is 10.8 μm. Magnetization in a static field H causes the domain structure to change in the usual way. Figure 1b shows a static domain structure in a field $H = 81.5$ Oe. The domain width d is 3.5 μm. The saturation magnetization is reached in the field $H_s = 91.5$ Oe. If an alternating square magnetic field $H_\sim$ is applied to a sample and its amplitude is gradually increased by using a frequency of 300 Hz, the domain walls initially will vibrate slightly and their motion will then become progressively faster and more random in nature. As a result, the domain structure becomes diffuse to such an extent that only a gray background is seen. Upon further increase in the field $H_\sim$ to 80–87 Oe, however, a system of randomly moving domain walls undergoes a self-organization, giving rise to the formation of clearly defined, high-contrast helical domains (Fig. 2). In a field $H_\sim > 87$ Oe, the domains again disappear. A comparison of Fig. 1b and Fig. 2 shows that the static and dynamic domain structures differ qualitatively in domain configuration.

It was shown experimentally that under dynamic conditions a sample can simultaneously have up to 5–6 helixes. The diameter of the helix core is 20–30 μm. The pitch of the helix in the neighborhood of the core is of the same order of magnitude. The area occupied by a helix can vary considerably. In Fig. 2a, for example, there is a single helix, ~1 mm in diameter, in the field of view of the microscope and in Fig. 2b

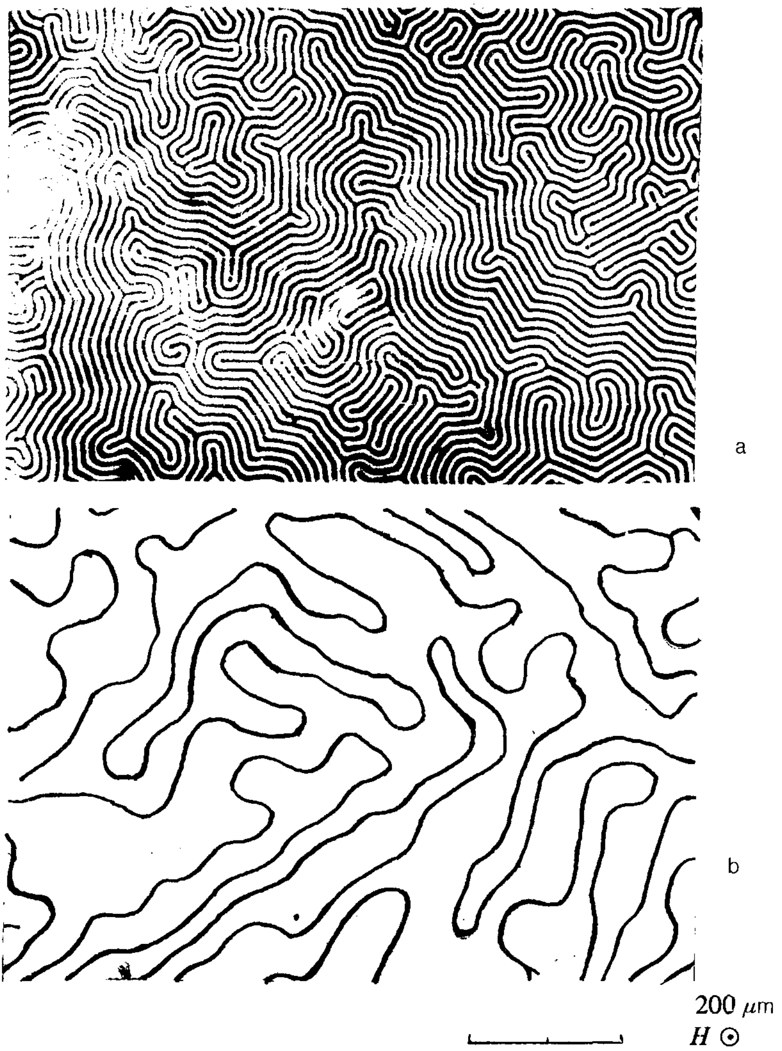

FIG. 1.

there are two helixes of smaller size. We see that the pitch of the helix decreases to 10–15 μm at the collision point of the helixes. In a field $H_\sim = 81.5$ Oe, the width of a single "dark" domain (Fig. 2) is the same, on the average, as that in the static field H of the same strength (Fig. 1b), i.e., $d_\sim = d = 3.5$ μm. There are clockwise and counterclockwise helixes. Figure 2b shows two helixes with different topological charges. When helixes with like or unlike charges converge, they become elastically deformed just as in the case of a collision of a helix with extended defects.

All the characteristic features described above concern the geometry of helical domain structures, whose unique feature is their dynamical undulating nature. The

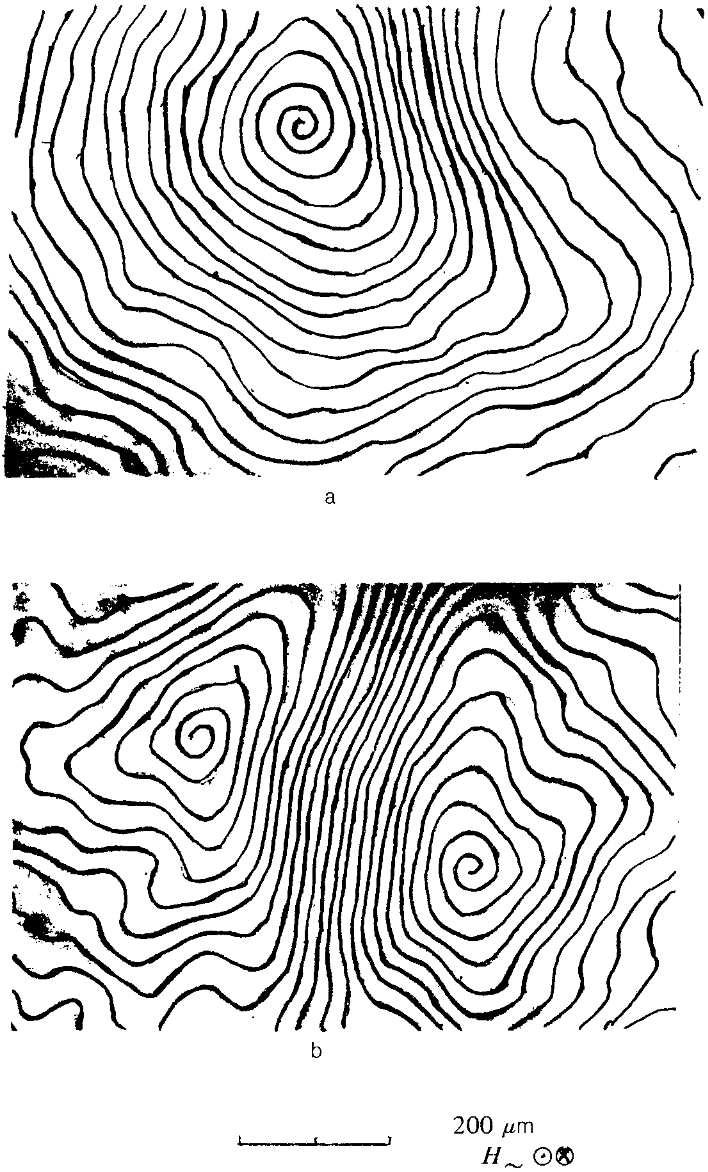

FIG. 2.

helixes are formed, are set in motion (swim), collide with each other or with some defects, disappear, and are formed again. The domain structures in Fig. 2 a and b, for example, are observed at the same point of the sample but separated by a time interval of several minutes. The helix core fluctuates from time to time, causing the helix to become uncoiled and its coils to move in an undulating manner. The lifetime of the largest spirals is ~ 10 s, i.e., dynamical domain structures of this sort are rather stable entities. The time between the appearance of two consecutive helixes (the wait time of a system) in an area of $\sim 1\ \mathrm{mm}^2$ is several seconds, on the average.

The photographs in Fig. 2 were taken with an exposure $\Delta t = 1.2$ ms, which is slightly shorter than the half-period of the alternating field. If the exposure time corresponds to the positive or negative half-period of $H_{\sim}(t)$, the photograph will show a "black" helical domain, as in Fig. 2, or a "white" helical domain with the magnetization directed toward the viewer or away from him, respectively. If the time Δt includes part of the positive and part of the negative half-period of the field, then both helixes with a common core can be seen simultaneously. If the external helix coils are not pinned to the defects, the helix can move smoothly along the sample at a velocity of several tens of microns per second. Finally, the formation of a dynamical domain structure will continue an arbitrarily long time if an alternating field is applied continuously.

The experimental data, taken collectively, thus show that the sample exhibits a special kind of excited state in a rather narrow interval of amplitudes of the alternating field, which is the pump field. This heretofore unknown state at least visually resembles the state corresponding to a self-propagating wave. The formation of dynamical (dissipative) helical structures is a manifestation of self-organization of a polydomain magnetic crystal in a highly nonequilibrium thermodynamic state. Although the particular features of the helical (rotational) domains are yet to be studied thoroughly, the features which are now observable suggest that these domains are similar to soliton structures.

Translated by S. J. Amoretty