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The peculiarities of bubble structures in ferrite-garnet films

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Peculiarities of the disordered bubble structures under temperature or magnetic field change have been studied. The experimental results are interpreted with in the concept of magnetistatic pressure. It is shown that the "memory effect" and the temperature range of stability depend on the degree of domain structure disorder and on structure of domain boundaries.

Изучены особенности неупорядоченных ЦМД-структур при изменении температуры или магнитного поля. При объяснении экспериментальных результатов используется концепция магнитостатического давления. Показано, что "эффект памяти" и температурный интервал устойчивости зависят от степени неупорядоченности доменной структуры и структуры доменных границ.

1. Introduction

In ferrite-garnet films there is a large variety of domain structures (DS) which can be subdivided into ordered and disordered DS. In the ordered DS, the domains are arranged in the long-range order. This class includes the hexagonal bubble-domain lattice (BDL), the honeycomb domain structure (HDs), the stripe DS, the hexagonal lattice of spiral domains, etc.

The disordered domain structure is a very large class of DS. In the disordered DS, the long-range order of domain arrangement fails. Depending on the degree of disorder the domain structure can be subdivided into three types: cluster, amorphous and cellular ones. The cluster BD structure is a structure consisting of a large of BDL blocks disoriented with each other or separated by stripes. There is no a clear-cut distinction between cluster and amorphous DS. If in a cluster the number of particles decreases to one, it transforms into amorphous structure. The amorphous structure consists of bubbles of different diameters, they are chaotically arranged in the film. The both structures are nonequilibrium with respect to concentration and defect distribution.

The paper describes the experimental study of disordered DS behavior and its domain boundaries (DB) under temperature (T) or magnetic field (H) change.

2. Results

The films of developed surface <111> were studied. Film No.1, composition $(TmBi)_3(FeGa)_5O_{12}$ (the Neel temperature $T_N = 437$ K, the temperature of magnetic compensation $T_C = 120$ K, saturation magnetization under the room-temperature conditions $4\pi M_S = 175$ Gs); film No.2 composition $(YSmLuCa)_3(FeGe)_5O_{12}$ ($T_N = 471$ K, $4\pi M_S = 258$ Gs). The domain structure was observed using the Faraday effect.

The experimental results are interpreted written the concept of magnetostatic field. The concept of the magnetostatic pressure of the bubble lattice was first introduced in [1], where bubbles are considered as particles of equal magnetic charge and located in the magnetic medium of opposite charge.

The repulsion forces are operating between the particles. Due to central forces of interaction there is bubble lattice. Just central forces of interaction between the bubbles that create the magnetostatic pressure of the lattice.

2.1. Effect of temperature on DS behavior

Fig. 1 represents the temperature dependences of magnetic characteristics of film No.1. Let us compare the temperature behavior of regular BDL, cluster and amorphous DS. The hole of the domain structures were formed at $T = 300$ K. The BDL was formed by the pulsed magnetic field normal to film plane (Fig. 2a). During T change the BDL was conserved in the interval ΔT. At the both ends of the interval, in the BDL the first-order phase transitions (PT) took place (Fig. 1) [2]. The PT at T_1 and T_2 have resulted in a disordered DS (Fig. 2b,c) which can also be treated as cluster one. With further changes in T, both at cooling and heating, the number of bubbles in clusters decreased, the degree of DS disorder became higher (Fig. 2d). Note that the number of bubbles was decreasing gradually in small jumps, as opposed to PT in BDL.

The amorphous DS was formed by constant magnetic field applied in parallel to film surface (Fig. 2e). when after switching the planar field off the film was influenced by a variable bias field, the bubble diameters became equal and there originated the cluster structure with slightly disordered BDL blocks and noticeable joints between the same (Fig. 2f). At the joints, the disturbance in the order of bubble distribution in the hexagonal lattice several defects were observed. The bias field was turned off. During T increase the cluster domain structure preserved to $T_1 = 370$ K, that is ΔT of the cluster DS is 30 degree higher than that of BDL. This is because the bubbles located near the isolated defect of BDL and the bubbles of cluster structure at joints between the blocks will be expanding faster than the rest ones because they are less influenced by the magnetostatic pressure. In the hexagonal BDL, the anisotropy of pressure results in transformation of the expanding bubbles into stripes and nucleation of a new phase. In the cluster DS, the pressure is to a high degree isotopic and the bubbles expand isotropically, so the transformation of bubbles into stripes is troublesome. In [3], the difference of temperatures for collapses of cluster and hexagonal bubble structures has been theoretically determined.

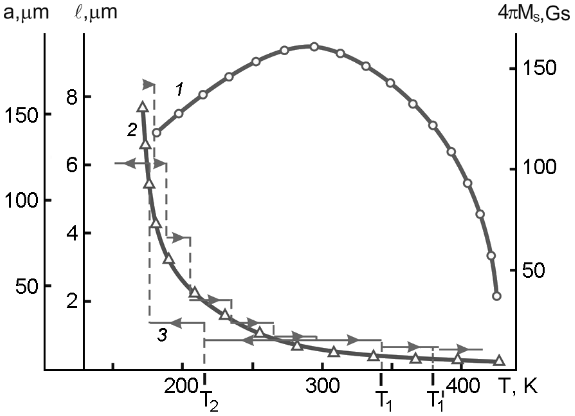

Fig. 1. Temperature dependences of film No.1: *1* — saturation magnetization, *2* — characteristic length, *3* — lattice parameters.

The evaluation of ΔT done according to [4] has resulted in $\Delta T \approx 50$ K. Thus, the temperature of the cluster bubble structure collapse should be higher than that for BDL collapse.

Under film cooling the process was opposite: the stripe length gradually decreased and at $T = 300$ K they contrasted into bubbles, i.e. the initial cluster structure has restores (the memory effect). Thus, in contrast to PT in BDL characterized by the temperature hysteresis, the temperature changes in cluster DS are reversible. This is because the temperature of first-order PT is close to the Neel temperature. In this temperature range, the pressure in cluster DS stops increasing, then follows pressure decrease and any transition similar to the irreversible PT in BDL is impossible.

Under heating, the amorphous bubble structure was preserved nearly to T_N and vanished near this temperature. In such a way, the amorphous bubble structure possesses the maximum temperature stability. This is explained by the fact in the amorphous structure, the pressure is more isotropic than in cluster one, so the stripes can't appear in this structure during T. Even the nuclei of stripes appeared, their size would be undercritical and inadequate for that T [5].

From the analysis of experimental results it follows that the higher DS is disordered, the larger its entropy and the higher temperature stability if possesses. It has been shown in [4] that even in the regular BDL with a small number of defects the entropy increases with T change and, as a result, the ordered structure transforms into disordered one. Thus, in the vicinity T_N and T_K, there should be a temperature

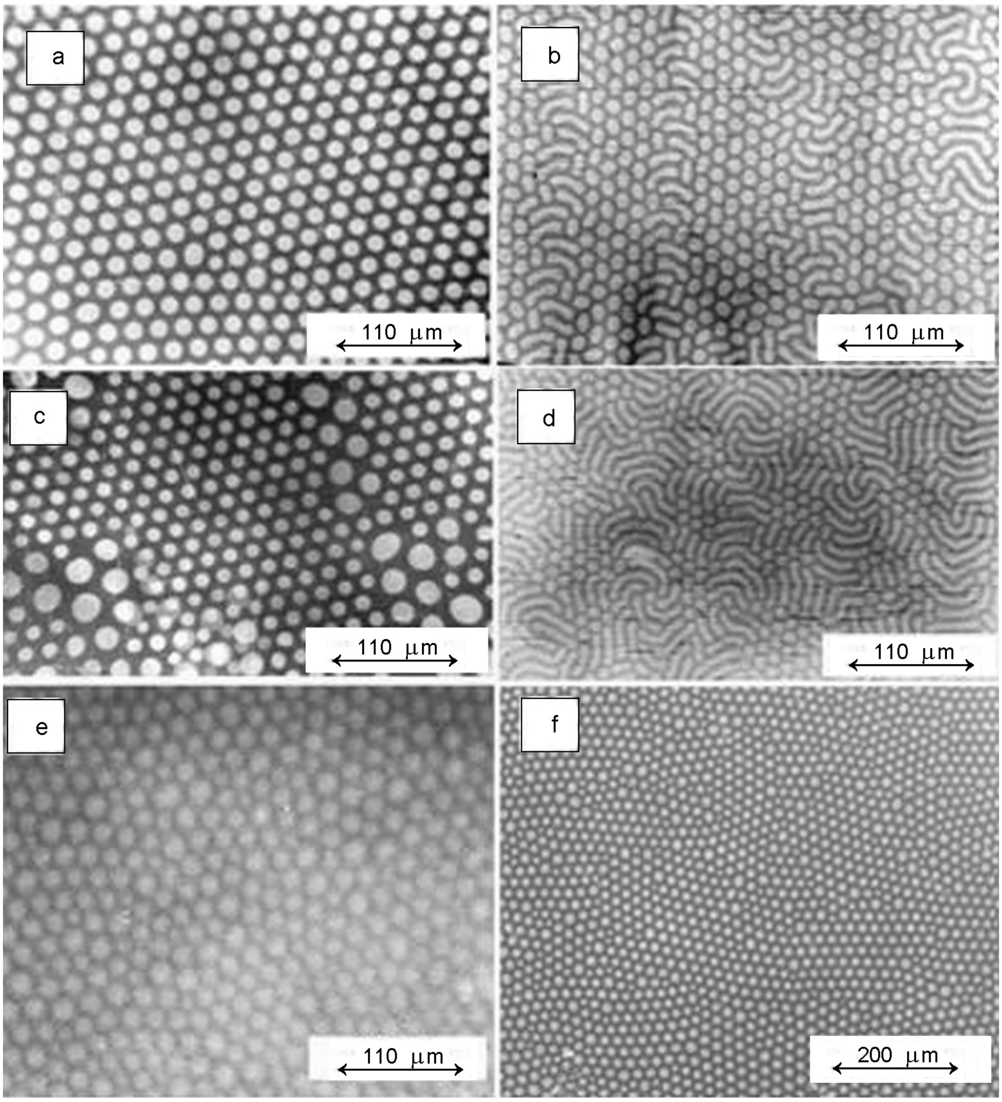

Fig. 2. Domain structure types for film No.1.

range where the BDL structure can't be formed since it will be in the amorphous state. Moreover, the formation conditions affect not only the properties of bubble structures but their domain boundaries. In the regular BDL formed by the pulsed magnetic field there are rigid and dumb-bell like domains, and domain boundaries of bubbles possesses high energy. These are thin 180-degree Bloch boundaries. In the cluster and all the more in the amorphous DS the rigid domains are absent and the bubble domains are not very clear, their energy is lower and are less stable.

2.2. Magnetic field effect on DS behavior

Disordered DS can be formed as a result of magnetic field-induced PT in BDL. In the film of composition $(YSmLuCa)_3(FeGe)_5O_{12}$, when the BDL was influenced by $H > 0$ (**H** antiparallel to magnetization **M** inside the bubble domain) the bubble diameter was decreasing and the period left constant. When H was equal to the collapse field (H_C) of BDL, every central bubble domain of the hexagonal packing disappeared, i.e. there was the first-order phase transition in the BDL. The disordered bubble domain structure, which has resulted from the PT, existed only for H_C. Its pressure is very low [6] that's why in the structure there appeared nuclei of stripes. After H decrease to zero a new disordered DS consisting of BD and stripes has originated. When H was for the second time increased to the field of BDL collapse, the stripes disappeared and the initial disordered BD-structure has restored. Under slow variation of H within $0 \leq H \leq H_K$ it was possible to realize transi-

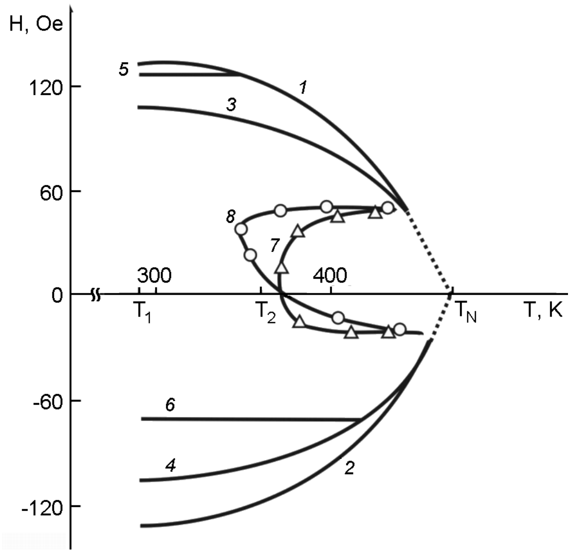

Fig. 3. H–T diagram of film №2: *1* — fields of the bubble collapse; *2* — fields of transition to monodomain state; *3,5* — fields of BDL_1 and BDL_2 collapse; *4,6* — fields of honeycomb DS_1 and DS_2 burst; *7,8* — T_{PT} for BDL_1 and BDL_2.

tion from one disordered DS to another, i.e. the disordered DS was reversible (possesses the memory effect) [7].

Interesting disordered DS were obtained from the honeycomb structure [8, 9]. The ordered honeycomb structure of two types was formed from BDL of two types. The both BDL were formed by pulsed magnetic field: the BDL_1 in the absence of bias field with subsequent H effect, BDL_2 — in the presence of H. Then the BDL were influenced by field $H < 0$ ($\mathbf{H}$ is parallel to $\mathbf{H}$ inside the bubble). The bubble diameter was increasing, the period remained constant. The bubble took the form of a hexagon in BDL — at 20 Oe, in BDL_2 — at 45 Oe. The resulting HDS_1 and HDS_2 (Fig. 4d) had different temperature intervals of stability and different values of the field of honeycomb structure burst (H_B) [8, 9] (Fig. 3). Under subsequent H growth, the domain size was increasing and for $H_{B1} = -105$ Oe the CDS_1 "burst", i.e. there was the first-order PT in HDS_1 [8]. The disordered cellular DS_1 (Fig. 4c) resulted from the PT was in the form of

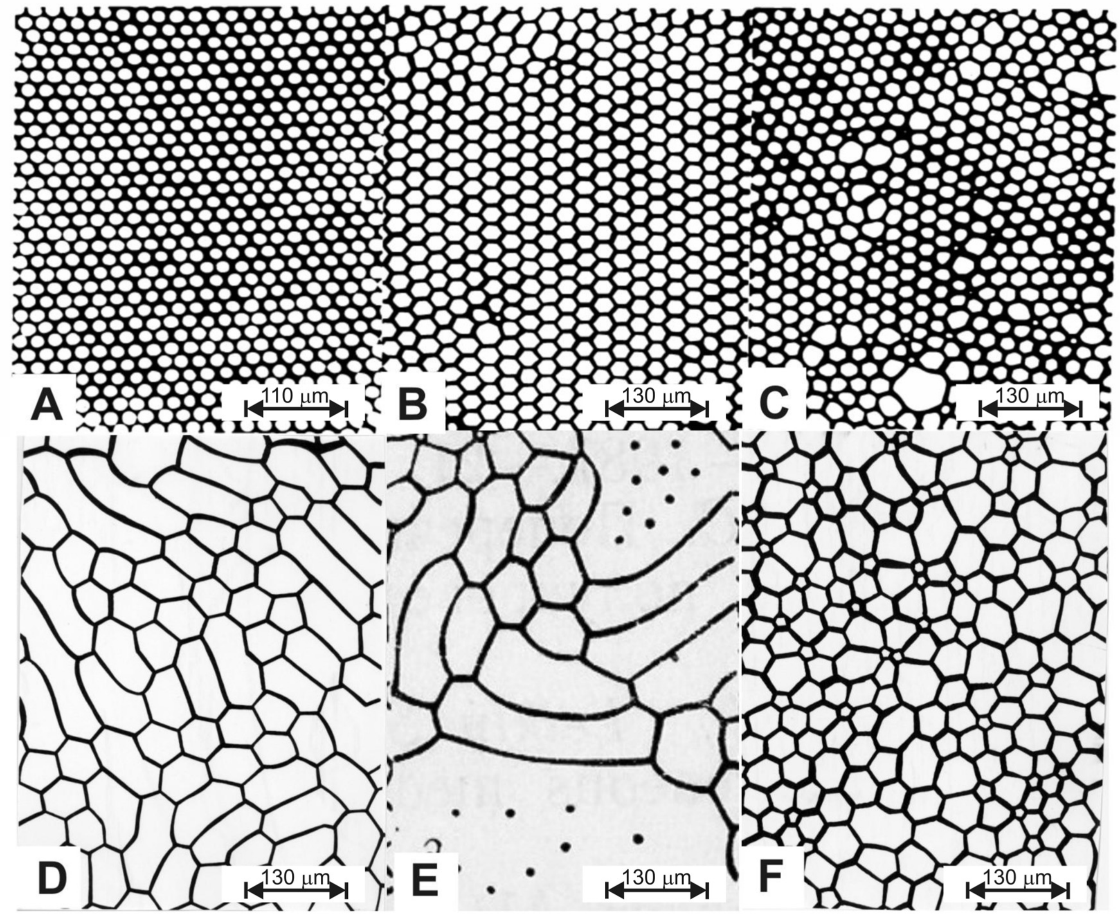

Fig. 4. All types of domain structures of film No.2.

irregularly located five and seven-petal "flowers". In each "flower" the central domain was small and round, the petals — large domains in the form of irregular polygon. When the cellular DS_1 was influenced by the pulsed magnetic field a new disordered structure appeared. It consisted of large domains in the form of prolonged hexagons resembling nets (Fig. 4d). Interdomain boundaries are stripes with magnetization antiparallel to **M** inside the domains. This is a very stable DS. Under the action of pulsed field, with $H < -120$ Oe, it was moving like nets against the wind but remained preserved. For $H = -120$ Oe and under the pulsed field this DS disappeared, instead there originated the BDL of low density of packing with the bubbles of opposite polarity (Fig. 4e). In such a way, a new BDL has formed from the stripes separating net cells. In this DS there was many dumbbell like domains.

The "burst" of HDS_2 took place for $H_{B2} = -70$ Oe, i.e. $|H_{B2}| < |H_{B1}|$ (Fig. 3). In HDS_2, the first-order PT has resulted in cellular HDS_2. This disordered DS_2 also was in the form of five-petal "flowers" interspersed with the seven-petal ones (Fig. 4f).

The disordered DS formed due to magnetic field-induced PT in HDS_1 and HDS_2 did not possess the memory effect though each DS was highly enough disordered. This is because the domain boundaries of the DS possess high energy because the initial structures were formed by the pulsed field.

At $T = 300$ K, the cellular DS was formed from the amorphous DS for $H < 0$. Then T of the film was increased. In contrast to HDS_1 and HDS_2, the cellular DS preserved to T_N. Such DS, possibly, satisfies the requirements necessary for the character of transition reversibility during H change since the structure is highly disordered and the energy of DB is low.

3. Conclusion

Analyzing the obtained results we can conclude the following. The higher the degree of disorder, i.e. the higher DS entropy, the higher its stability during temperature or magnetic field change. This refers the domain boundaries as well. The lower the external influence (in particular by the pulsed field), the more probable the reversibility for DS transitions, i.e. the "memory effect" is present.

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Особливості ЦМД-структур у ферит-гранатових плівках

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Вивчено особливості неупорядкованих ЦМД-структур при зміні температури або магнітного поля. При поясненні експериментальних результатів використано концепцію магнітостатичного тиску. Показано, що "ефект пам'яті" і температурний інтервал стійкості залежать від ступеня неупорядкованості доменної структури і структури доменних меж.