

Spin-reorientation phase transition in ferrite-garnet films of different axial anisotropy

Ju.A.Mamalui, Ju.A.Siryuk, A.V.Bezus

Donetsk National University, 24 Universitetskaya Str., 83001 Donetsk, Ukraine

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The mechanism of spin-reorientation phase transition (SRPT) in ferrite-garnet films has been studied. Changes in structure of domain boundaries during phase transition have been investigated. Domain structure models appropriate for the experiment have been proposed. It has been shown that the phase transition through nucleation in the domain boundary induced the first-order phase transition from axial to angular phase. The SRPT mechanism does not depend on the value of ratio between anisotropy constants.

Изучен механизм спин-переориентационного фазового перехода (СПФП) в феррит-гранатовых пленках. Исследовано изменение структуры доменных границ при фазовом переходе. Предложены соответствующие эксперименту модели доменной структуры. Показано, что фазовый переход путем зародышеобразования в доменной границе вызывает СПФП I рода из осевой фазы в угловую фазу. Механизм СПФП не зависит от величины соотношения между константами анизотропии.

1. Introduction

Ferrite-garnet films possess mixed anisotropy: along with the crystallographic cubic one (K_1) there exists the uniaxial anisotropy (K_u) induced during film growth. The axis of the growth-induced uniaxial anisotropy <111> is oriented perpendicularly to film plane. Three axes of the crystallographic anisotropy <111> are oriented at an angle to film plane. The ratio of uniaxial and cubic anisotropy constants as well as saturation magnetization depend on temperature: K_u/K_1 and $M_S()$. For magnetic compensation and the Neel temperatures, T_C and T_N, respectively, the saturation magnetization is zero. Domain structure (DS) is very sensitive to changes in magnetic characteristics of films, it changes with anisotropy and magnetization. It is therefore of interest to study DS behavior close by the critical temperature where magnetic moments of sublattices are equal (T_C) or where there are changes in anisotropy (T of spin reorientation). As the epitaxial films are optically transparent, the DS can be visualized by the Faraday Effect, whereas the spin reorientation is detected by the method of colour registration. Thus, ferrite-garnet films can be used as model objects phase transitions (PT) and spin-reorientation phase transitions (SRPT).

An influence of mixed anisotropy on DS behavior has been not enough studied. In [1–5] the spin-reorientation phase transition on labyrinth DS in ferrite-garnet films has been experimentally studied. The broadening of domain boundary between collinear phases with further boundary transformation to the noncollinear phase at spin reorientation has been observed in [1]. In [2, 3] changing of internal structure of domain boundaries has been detected. This change occurs under the restructuring of DS at spin-reorientation phase transition. In [4, 5] the hysteresis-free SRPT occurs from "easy axis" anisotropy type to "easy plane" one.

There was 3K region of two phase coexistence. However, in [1–5] the possibility of boundary absence between axial and angular phases was not indicated. In contrast to [1–5] we have made an investigation of SRPT on cylindrical magnetic domains (bubbles) in film with strong uniaxial anisotropy [6, 7]. This investigation allowed to detect two facts: 1 — the domain boundary of the axial phase is the nucleus of angular phase; 2 — there is no visual boundary between axial and angular phases.

Two types of SRPT in the film with low axial anisotropy on equilibrium DS which created by pulsed magnetic field at each temperature was investigated by us in [8]. The simulation method of domain boundary was used to explain the experimental data. Present paper is a continuation and extension of the earlier works [6–8]. The researches have been conducted on nonequilibrium DS in two magnetic film with different axial anisotropy. The SRPT occurs by only temperature change of anisotropy constants without supplementary energy of magnetic field.

For both the fundamental and the applied science it is very important to be aware of DS behavior during anisotropy change and of domain boundary (DB) changes. Such studies are very urgent. First of all, the SRPT can be used for thermomagnetic recording at the point of spin reorientation [9]. Secondly, near the SRPT, many physical quantities (heat capacity, magnetic susceptibility, the Young's modulus, attenuation factor, etc) become anomalous [10]. So, with such a magnetic material, the operation range of device can be limited. The paper is aimed at studying the mechanism of spin-reorientation phase transition.

2. Description of the investigation results

To attain the aim we have studied an influence of mixed anisotropy on peculiarities of domain structures of ferrite-garnet films with different axial anisotropy in the 90 K – T_N temperature range. The results are given for the two films. Film No.1 with a weak uniaxial anisotropy having the composition $(YBi)_3(FeGa)_5O_{12}$ (T_N = 421 K, point of magnetic compensation T_C = 223 K and saturation magnetization under the room-temperature conditions $4\pi M_S$ = 110 Gs) with axial phase in a narrow temperature range for $T > 360$ K. Film No.2 with a high uniaxial anisotropy having the composition $(TmBi)_3(FeGa)_5O_{12}$ (T_N = 437 K, T_C = 120 K, $4\pi M_S$ = 175 Gs) under the room-temperature conditions) with the axial phase in a broad temperature range for $T > T_C$. The easy magnetization axis is <111>. The domain structure is observed using the Faraday Effect. Spin-reorientation phase transition is detected by the method of colour registration. Features of SRPT in the films have been studied. The experimental data have been used to construct the models of domain structures and domain boundaries.

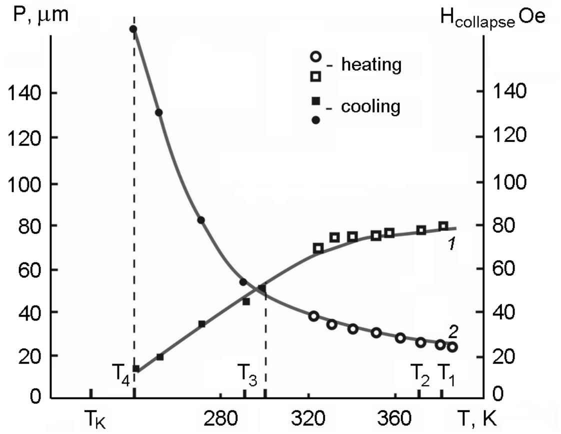

Fig. 1. Temperature dependences of physical parameters for film No.1: *1* — collapse field; *2* — DS period.

Film No.1. In the temperature range $T_1 - T_2$ (Fig. 1) the bubble lattice is formed by the pulsed magnetic field normal to the film plane (Fig. 2a), then the magnetic field is switched off. Formation of bubbles points to an existence of axial phase in this temperature range. We observe dark-green bubbles against the orange field. These are the axial phases. At T_2, some sections of domain boundary become broader and to the both sides from the sections we observe changes in colour of the field (from orange to yellow) and of the bubbles (from dark-green to green) (Fig. 2b). This is the first-order SRPT from the axial phase to the angular one [7]. The spin-reorientation phase transition originates from the domain boundary. The broadened section of the bubble domain boundary is a nucleus of the angular phase. The SRPT in the whole sample was induced by phase transition in DB itself. The two transitions are interrelated. The axial and angular phases coexist in the temperature range ΔT = 15 K. Note that the boundary between axial and angular phases is not visual.

DS models explaining its features in the range 400 K – T_C (Fig. 3) are proposed. In

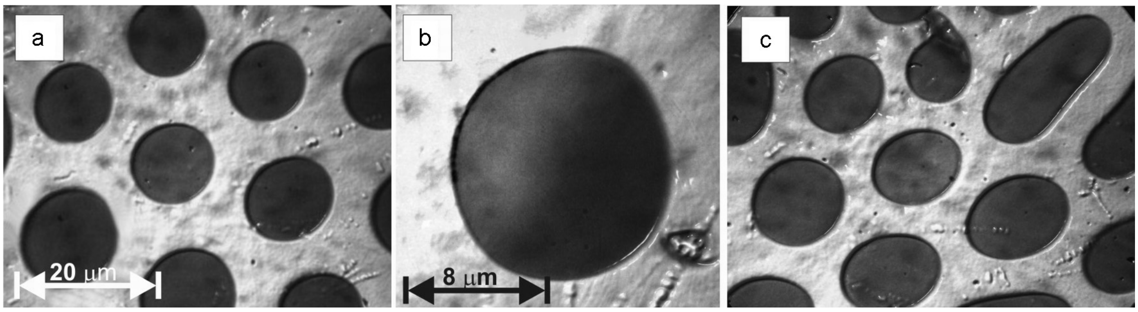

Fig. 2. Types of DS for film No.1 during T change: A — bubble lattice, 370 K; B — bubble, 365 K; C — DS, 290 K.

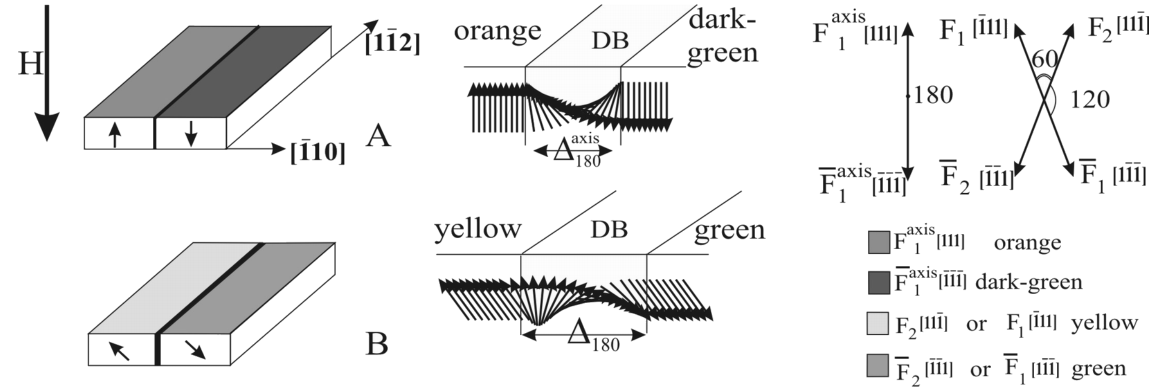

Fig. 3. Models of domain structures and magnetization distribution in domain wall: A — axial; B — angular.

the range $T_1 - T_2$ (Fig. 1) there are two axial phases F_1^{axis} <111> and $\overline{F}_1^{axis}$ <$\overline{111}$. The domain boundary is 180° Bloch one (Fig. 3a). The uniaxial anisotropy decreases during cooling to T_2. At some sections of bubble boundaries the orientation of spin changes under the influence of cubic anisotropy. This results in changes of spin orientation in regions close to the domain boundary, i.e. we have changes in the colours of field and bubbles (Fig. 2b). The angular phases F_1 <$\bar{1}$11> (yellow) and $\overline{F}_1$<1

$\overline{11}$> (green) originate. Thus, the cubic anisotropy induces phase transition in the domain boundary, which, in turn, initiates the SRPT from axial phase to angular one in the whole sample. In this case, the domain boundary of the axial phase is the nucleus of the angular phase. The SRPT from axial phase to the angular one occurs through nucleation. After the phase transition the domain boundary is still the 180° one, but its plane is oriented at an angle to axis <111>. In this case, 180-degree turn of the spins happens in a broader DB (Fig. 3b). Such transition in the domain boundary corresponds to its minimal energy.

Film No.2. The bubble lattice has been formed at 215 K. Two axial phases F_1 and F_2 have been obtained: the orange bubbles against the brown field. At 185 K some sections of the bubble round boundaries have become broader. At the sections, the field colour has changed from brown to green, that of the bubbles — from orange to white. This is indicative of the beginning of spin reorientation process and of the two new phases origination with the magnetization vectors directed at an angle to film plane: F_3 <1$\overline{11}$> — white colour of bubbles and F_4 <$\bar{1}$11> — green field.

In the film with high uniaxial anisotropy, the hysteresis-free SRPT from axial to angular phase is observed. Thus is the first-order SRPT [7]. The same as in sample No.1, the angular phase nucleates from the 180-degree domain boundary. The SRPT is induced by the phase transition in DB. Axial and angular phases coexist at 25 K. There is no boundary between axial and angular phases.

3. Results and discussion

The results of the studies showed that changes in the ratio of anisotropy constants K_u/K_1 with temperature resulted in changes of the structure of domain boundaries and in the type of domain structure, i.e. phase transitions in domain boundaries as well as spin-reorientation phase transitions oc-

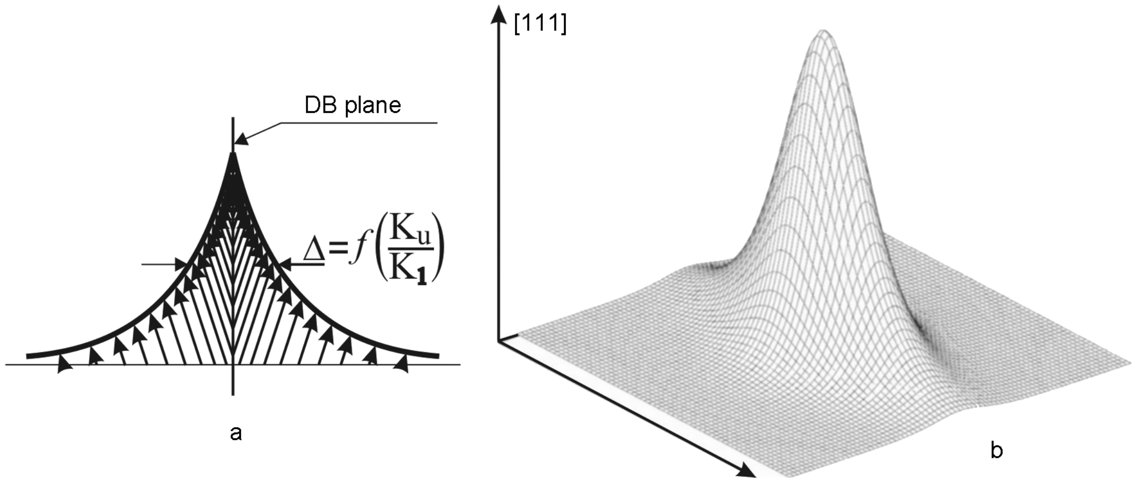

Fig. 4. Static soliton: *A* — distribution of spins; *B* — three-dimensional presentation.

curred. It was determined that domain boundaries are the most sensitive to the temperature changes in K_u/K_1. At the domain boundary the orientation of spins is highly alternate. At the specific temperature the corresponding orientation of spins at the domain boundary becomes the most advantageous from the energy viewpoint. Thus, the rearrangement process, i.e. phase transition is induced. The phase transition at the domain boundary induces the spin-reorientation phase transition in the whole sample. The character of phase transition at the domain boundary specifies the mechanism of SRPT.

Peculiarities of the SRPT from axial to angular phase are explained by the presenting a new phase nucleus as a static soliton which is growing in size with changes in the ratio of anisotropy constants (Fig. 4). In [11, 12], the static soliton is represented as magnetic inhomogeneity where density of spin distribution exponentially decreases with distance. Such inhomogeneity with a definite spin orientation, which corresponds to angular phases, originates in the central point of the domain boundary. As the density of spin distribution exponentially decreases with distance, there is no jump in the density of spins of the angular phase at the axial phase — angular phase interface. So, the boundary between the phases is not visual. Consideration of a new-phase nucleus as a static soliton helps in understanding the character of phase transition at the domain boundary and in explaining the visual absence of a boundary between axial and angular phases. Studies of the mechanism of SRPT in the samples of different uniaxial anisotropy value showed that the mechanism of SRPT from axial to angular phase does not depend on the value of ratio between anisotropy constants.

4. Conclusions

It has been visually proved that in ferrite-garnet films the mechanism of hysteresis-free first-order SRPT from axial to angular phase has occurred through nucleation. A "new" phase nucleates from the boundary of original phase. There exists the temperature range where axial and angular phases coexist. The boundary between the phases is not observed. The absence of boundary between axial and angular phases is for the first time explained by the representing a new phase nucleus as a static soliton which growing in size with changes in the ratio of anisotropy constants. It has been shown experimentally that the spin-reorientation phase transition from axial to angular phase has occurred in the similar way in the films of different uniaxial anisotropy value. The SRPT mechanism does not depend on the value of ratio between anisotropy constants.

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Спін-переорієнтаційний фазовий перехід у ферит-гранатових плівках з різною осьовою анізотропією

Ю.О.Мамалуй, Ю.А.Сірюк, О.В.Безус

Вивчено механізм спін-переорієнтаційного фазового переходу (СПФП) у ферит-гранатових плівках. Досліджено зміну структури доменних меж при фазовому переході. Запропоновані моделі доменної структури, які відповідають експерименту. Показано, що фазовий перехід шляхом зародкоутворення у доменній межі спричиняє СПФП I роду із осьової фази у кутову фазу. Механізм СПФП не залежить від величини співвідношення між константами анізотропії.