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The electromagneto-optical effect in local areas of single magnetic domains in epitaxial films of yttrium iron garnet

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The local electromagneto-optical effect (EMOE) from different sites of separate magnetic domains in the epitaxial films of yttrium iron garnet is investigated. These investigations show that value of the local EMOE is not stable in the course of optical scanning of different sites of magnetic domain. Separate points of the films are found out where changes of the EMO signal in the form of separate narrow peaks are clearly registered. In our opinion, those local points are the defect areas in the sample and the EMOE method allows us to reveal defects in the films and to determine their arrangement.

Исследован локальный электромагнито-оптический эффект (ЭМОЭ) на различных участках отдельных магнитных доменов эпитаксиальных пленок железоиттриевого граната. Показано, что величина локального ЭМОЭ не остается постоянной в ходе оптического зондирования различных участков магнитного домена. Выявлены отдельные точки на пленках, где ясно регистрируются изменения ЭМО сигнала в виде узких пиков. По нашему мнению, указанные локальные участки, это области дефектов в исследуемой пленке, и ЭМОЭ метод позволяет нам выявлять эти дефекты и определять их размещение.

1. Introduction

Single crystal yttrium iron garnet (YIG) films as magnetic insulators grown by liquid phase epitaxy (LPE) are used widely as materials for memory devices and remain interesting for microwave applications until now. A single crystal of gadolinium gallium garnet (GGG) has nearly the same lattice constant as YIG, and has for this reason become the prime substrate for epitaxial growth of garnet films. YIG belongs to magnetics among numerous materials where the magnetoelectric effect (MEE) is observed [1–3]. In [4–7], devoted to study of MEE in YIG by optical methods (electromagneto-optical effect), connection between the specified effect and magnetisation processes in YIG has been shown. We also focused attention on the important role of the domain structure (DS) at registration of the MEE (EMOE), as the integral EMO effect from multidomain sites actually is a consequence of DS changes induced by the electric field [5]. These changes of DS are manifested as small displacements (change in positions) of the domain wall (DW), caused by the *E*-field. Thus, the external electric field can be considered as an additional control path of YIG magnetic condition.

In this work, the results of the further local EMOE researches in separate magnetic domains are presented. As it has been shown by us before [5], the local EMO effect is connected with the influence of the electric field on the YIG magnetic anisotropy. A high sensitivity of YIG domain structure (domain walls) to of the magnetic anisotropy changes caused by electric field action allows to register MEE (EMOE) [5, 8].

2. Experimental

Our experimental technique combining the laser polarimetry and a polarising microscopy is described in details elsewhere [5]. This technique allows us to measure the local changes of light polarization plane rotation (Faraday rotation) under action of variable low-frequency electric field applied to the sample (α_{EMO} parameter). In this case, $\alpha_{EMO} \sim a_1 M_{loc} + a_2 B_{loc}$, where M_{loc} is local magnetization; a_1 and a_2 are certain coefficients $B_{loc} \sim H_{int.loc}$ is the local value of the magnetic induction ($H_{int.loc} = H_{ext} - H_{demag}$, where H_{demag} — the demagnetization field that will be not uniform in the case of a multidomain film). In our experiments, YIG film was used grown by liquid phase epitaxy on GGG substrate. The film thickness was about 10 μm, and thickness of the GGG substrates for film was about 600 μm. Experiments were carried out at room temperature in longitudinal geometry ($\mathbf{E}\|\mathbf{k}$, $\mathbf{H}\|\mathbf{k}$, where $\mathbf{k}$ is the light wave vector, $\mathbf{H}$ is a static magnetic field, $\mathbf{E}$ is a variable electric field ($\omega = 900$ Hz)). The domain magnetisation in the film was normal to the film plane. A He–Ne laser ($\lambda = 0.63$ μ) was used in the experiments and using of a round diaphragm [5] allowed us to allocate the sites of about 3 μm in diameter in the film.

3. Results and discussion

Fig. 1 shows the magnetic field dependence of the EMOE measured in an arbitrarily selected separate magnetic domain of the investigated YIG film, without DW in the area of laser scanning, when $E_{\sim} = 3$ kV/cm. Only the 2ω component of the EMOE signal was detected in our sample. The measurements were carried out for two magnetic field directions, $H\uparrow\uparrow M$ and $H\uparrow\downarrow M$. In what follows, when discussing EMOE, we will be limited to a section of the magnetisation curve preceding the magnetic saturation. This limited section is marked by vertical dashed lines in Fig. 1. In the specified range of magnetic fields, the EMO signal practically does not change, thus, the effect is independent of the magnetic field. However, at similar laser beam probing of other local areas of this film within the chosen domain (not touching DW), it has been revealed that at invariable character of the magnetic field EMOE dependences, the EMO effect value did not remain a constant. The specified feature demanded additional researches.

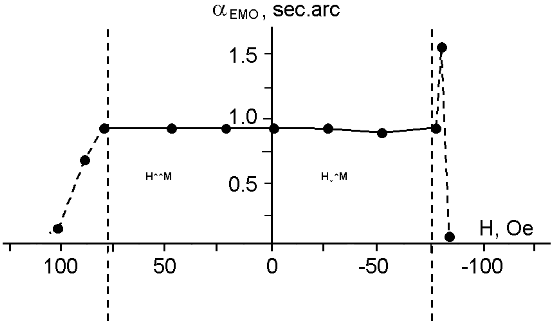

Fig. 1. The magnetic-field dependences of EMOE for YIG film measured on the central site of domain.

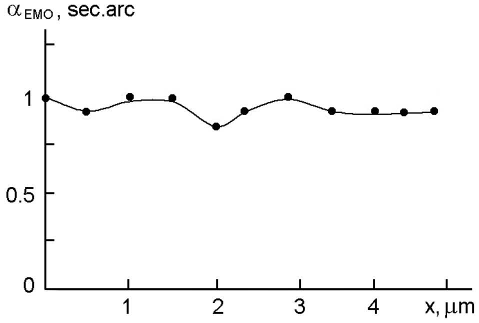

Fig. 2. The changes of the EMO parameter for the different sites of the magnetic domain when the scanning diaphragm moving of in cross-section direction **X** (in relation to DW).

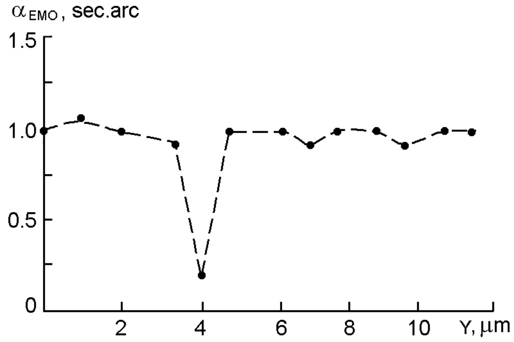

Fig. 3. The changes of the EMO parameter for the different sites of the magnetic domain when the scanning diaphragm moving of in a longitudinal direction **Y** (in relation to DW).

Fig. 2 and Fig. 3 present dependences of the EMO signal changing $H = 0$ Oe, $E = 3$ kV/cm) at moving of the scanning diaphragm over the central areas of the magnetic domain in cross-section direction X (in relation to DW) and in longitudinal direction Y. The starting points for optical scanning are selected arbitrarily. As is seen from the presented curves, the EMO signal value in some scanning points differs from the average signal level over the domain. In these dependences, changes of the EMO signal in the form of separate narrow peaks are clearly visible. In our opinion, the revealed local changes of the EMOE value can be explained as follows. External electric field does not change the spontaneous magnetisation value in YIG [5]. Hence, the Faraday rotation value changing in electric field that we experimentally observe (α_{EMO} parameter), at invariable magnetisation depends on the value of demagnetization fields in vicinity of the point of optical scanning.

We discuss the local EMO effect, but the external E-field is applied not to concrete observed area but to the sample as a whole. That is, actually we deal with integrated ME (or EMO) effect which is manifested to different extent only in the presence of domain structure in the sample and it is very sensitive to relative positioning of DW and points of optical scaning [5, 6]. Initially, in the multidomain sample, there is a complicated picture of local demagnetization fields distribution, appearing in a film domains due to of presence of magnetic heterogeneities. The variable E-field, influencing the magnetic anisotropy of a film as a whole, sets the domain walls in motion that, in turn, results in redistribution of local demagnetization fields in domains. Registration of stable EMO signal in the domain is a result of the above processes. Disappearance or essential reduction of the signal in separate points in the domain against a stable signal in the neighboring points of the same domain can testify to presence of an abrupt change of the demagnetization field in the given point of the area.

As it is seen from Fig. 2 and Fig. 3, we have revealed separate small sites in the film where stability of the EMO signal in the centre of domain is violated though EMOE in the domain should not change its value. This may occur at irregular change of local value of the demagnetization field in a scanning point, for example, at presence of DW (as magnetic heterogeneity) in the area of laser probing. But DW does not get to this area, since the domain structure is monitored visually. We assume that the area of defect which is captured by a laser beam can be the specified magnetic heterogeneity. In the sites of irregular changing of the magnetisation vector near to defects (inclusions and pores) exist local demagnetization fields and magnetisation difference in these points causes a change of magnetostatic energy (energy in the local demagnetization field). Thus, combination of the demagnetization fields and nonuniformity of parameters results in registration of EMOE local changes in separate points in the magnetic domain YIG film.

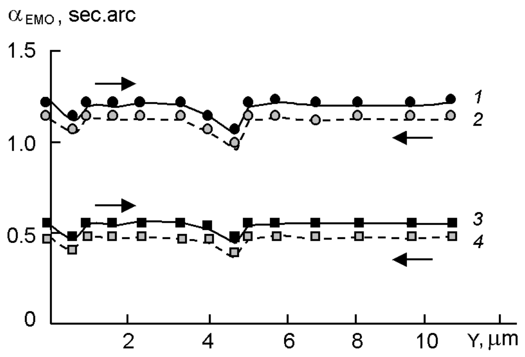

Fig. 4. The changes of the EMO parameter for the different sites of the YIG film magnetic domain (after thermal influence) when the scanning diaphragm moving of in a longitudinal direction **Y** (in relation to DW).

The experiment similar to that which results are presented in Fig. 3 has been made also on the same sample of YIG film subjected to thermal annealing. In [9], we have presented the results of preliminary experiments where thermal annealing to integrated EMOE of YIG films was studied. The annealing was carried out for 240 minutes at temperature 853 K with the subsequent slow cooling. The results of measurements where the scanning diaphragm was moved in longitudinal direction in relation to DW in the domain (the Y direction) are presented in Fig. 4 (curve *1*: $E_\sim = 3$ kV/cm, $H = 0$ Oe; when curve *2*: $E_\sim = 2.75$ kV/cm, $H = 0$ Oe; curve *3*: $E_\sim = 2$ kV/cm, $H = 0$ Oe; curve *4*: $E_\sim = 1.75$ kV/cm, $H = 0$ Oe). Measurements were carried out both in the forward and in the reverse movement (directions are designated by arrows in Fig. 4). The starting points for optical scanning, as well as in the previous experiments, was selected arbitrarily. As is seen from Fig. 4, the average level of EMO signal over the domain is slightly increased in comparison with results prior to annealing. The EMO signal value over the domain as a whole is unstable, though no such sharp signal changes are revealed what were registered prior to temperature influence. Change of the external magnetic field in the range from 0 to 60 Oe (at $H\uparrow\uparrow M$ and at electric field values of specified in Fig. 4) did not influence the value of registered EMO signal. The insignificant increase in average level of the EMOE in domain may be due to temperature influence on shape anisotropy induced in the course of YIG film growth that demands additional researches.

4. Conclusion

Thus, the high sensitivity of the optical polarimetry and small changes of YIG magnetic anisotropy in the external low-frequency electric field detected by the specified method (magnetoelectric effect) allow to reveal local magnetic heterogeneity in YIG films without use of external magnetic fields which can "destroy" these heterogeneity. When probing by laser beam various sites of the film, it is possible to control the defects and to determine their arrangement in corresponding samples using the EMO signal level.

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Електромагніто-оптичний ефект на локальних ділянках окремих магнітних доменів епітаксійних плівок залізоітрієвого гранату

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Досліджено локальний електромагніто-оптичний ефект (ЕМОЕ) на різних ділянках окремих магнітних доменів епітаксійних плівок залізоітрієвого гранату. Показано, що величина локального ЕМОЕ не залишається стабільною при оптичному зондуванні різних ділянок магнітного домену. Виявлено окремі точки на плівках, де чітко реєструються зміни ЕМО сигналу у вигляді окремих вузьких викидів. Ми вважаємо, що вказані локальні точки – це області дефектів у плівці, що досліджувалася і ЕМОЕ метод дозволяє нам виявити ці дефекти і визначити їхнє розміщення.