Photoinduced polarization-dependent change in the domain structure of an iron garnet film

V. P. Sokhatskiĭ and V. F. Kovalenko
Taras Shevchenko Kiev University, 252017 Kiev, Ukraine

(Submitted 10 May 1995)
Pis'ma Zh. Éksp. Teor. Fiz. **61**, No. 12, 988–991 (25 June 1995)

It was found that the domain structure of a Bi-containing iron garnet film at room temperature changes under the action of linearly polarized light. The accompanying change in the magnitude of the magnetization of the film depends on the intensity and the orientation of the polarization plane of the irradiating light. The effect is associated with the photoinduced deformation produced in the crystal lattice by polarization-sensitive charge transfer on magnetically anisotropic impurity centers.

In Ref. 1 we reported the observation of a polarization–dependent change in the domain structure of single-crystalline silicon-doped iron yttrium garnet (YIG:Si) at cryogenic temperatures (77 K), and later observed at temperatures of up to 140 K. After observing the effect of linearly polarized light on the magnetic characteristics of Co-doped iron garnet films at room temperatures,[2] we investigated photoinduced (PI) magnetic effects in materials with a wider range of values of the parameters and for parameters which are more suitable for the existence of the effect. These experiments led to the observation of "high-temperature" photoinduced defects in iron garnet films.

In the present paper we report the observation of photoinduced change in the domain structure and magnetizaton at room temperature of $(Bi, Tm, Lu)_3Fe_5O_{12}$ films irradiated with polarized light from both monochromatic (He–Ne-laser with a wavelength of 0.63-μm and cw radiation power of 1 mW) and nonmonochromatic (incandescent lamp) sources of radiation. The films were of the order of 5 μm thick and were grown epitaxially in the (100) plane on a gadolinium-gallium garnet substrate. The standard procedure of magneto-optic investigations, based on the Faraday effect, with slightly uncrossed polarizer and analyzer was implemented on an apparatus that makes it possible to observe visually and record the patterns of the domain structures at different stages of irradiation of an iron garnet film at the same time by performing photometric measurements on the polarized low-intensity reading beam transmitted through the film. Figure 1a shows the geometry of the directions of the polarization of the irradiating light and the magnetization vectors in domains relative to the crystallographic axes [011] and [0–11], which are the easy-magnetization axes (EMA) in the (100) plane. To produce the longitudinal (Faraday) component of the magnetization in the direction of propagation of the reading beam, the reading beam was directed at an angle to the plane of the film.

As a result of the irradiation of a section or the entire surface of the magnetized film by polarized light, whose polarization plane was directed parallel to the [011] axis, the magnetic domains in which the magnetization vector was oriented in this direction in-

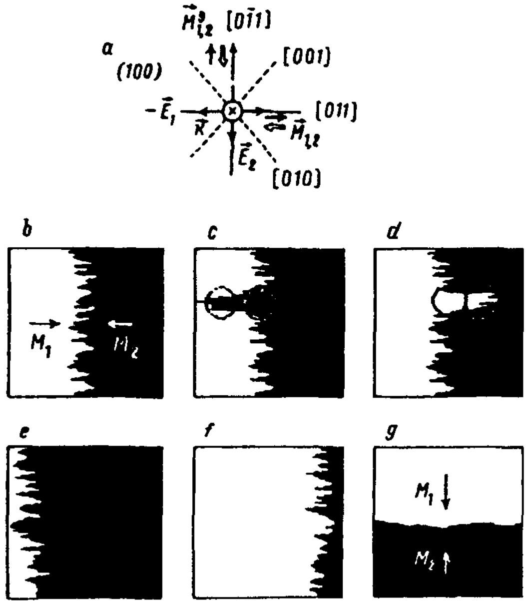

FIG. 1. Domain structures of iron garnet film (b) with orientation of the axes relative to the direction and polarization of the beam (a) after irradiation of local sections of the film (the wavy lines mark successive positions of the laser spot) and the entire surface of the film (*e,f*) (a large part of the domain structure of the film is shown) with light with $\mathbf{E}_1 \parallel [011]$ (c, e) and $\mathbf{E}_2 \parallel [0-11]$ (d, f), as well as after the magnetic moments are reoriented in the direction of the other easy-magnetization axis (*g*).

creased in size and the domains with oppositely directed magnetization decreased in size (Fig. 1b–f). Typical curves of the magnetic polarity reversal in a local region of the film under the action of polarized light with different intensities are shown in Fig. 2. We note that magnetization up to saturation in a local region occurs only up to a threshold value of the residual magnetization of the film. A further increase of the magnetization is

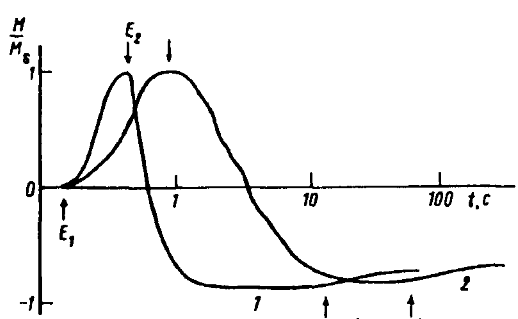

FIG. 2. Magnetization reversal in the section of the film under the action of light with $\mathbf{E}_1 \parallel [011]$ and $\mathbf{E}_2 \parallel [0-11]$ and different intensity: *1*—10 W/cm^2; *2*—0.2 W/cm^2. Arrows—light with the corresponding polarization switched on and off.

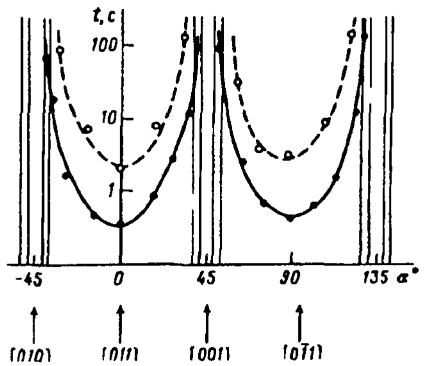

FIG. 3. Rearrangement time of a domain structure in a section of the demagnetized film plotted as a function of the angle between the [011] axis and the direction of the polarization plane of light with the same intensities as in Fig. 2.

prevented by an increase of the demagnetizing fields. As the intensity of the light increases, the resulting residual magnetization of the film increases in proportion. The observed change in the domain structure is similar to the restructuring that occurs under the action of external magnetic fields of different magnitudes, although in the present experiment no additional action giving rise to magnetization (with the help of either constant or alternating magnetic fields, as for example in Ref. 2) was employed. At the same time, the influence on the described effect of an external constant magnetic field weaker than the saturation field of the domain structure of the film is manifested, correspondingly, as a decrease or increase of the photoinduced rearrangement time of the domain structure with the field oriented parallel or antiparallel to the increasing magnetization vector. The domain structure of the film magnetized by the light remains after the light is switched off (with the exception of the weak relaxation of the residual magnetization, marked by the bottom arrows in Fig. 2, after the irradiation is switched off) and can be repositioned into its initial position by repeated irradiation with light polarized orthogonally to the initial polarization and directed along the other easy-magnetization axis [0−11]. The minimum energy density of the light required for restructuring did not exceed 0.1 J/cm^2, and the characteristic restructuring time, ranging in the present experiment from fractions of a second to several tens of seconds, decreased in proportion to the increase in the irradiation intensity. Depending on the magnitude of the magnetization, these times can also change by approximately two orders of magnitude compared with case of a demagnetized film. It is evident from the polarization characteristic of the effect (Fig. 3) that irradiating a film with light whose polarization vector is directed along the [010] and [001] axes did not appreciably affect the domain structure.

In our experiments we also observed other manifestations of the photoinduced change in the domain structure, such as, the rearrangement shown in Fig. 1g, a consequence of the polarization-dependent reorientation of the magnetic moment vectors in the direction from one easy-magnetization axis to another in the (100) plane. Such a restructuring occurs when a small constant magnetizing planar field (which remains constant throughout the experiment) is applied and the film is irradiated with light polarized along the corresponding easy-magnetization axis. Distinguishing features of this case are that the iron garnet film remains demagnetized and the radiation energy density and reorientation time are an order of magnitude smaller than in the preceding case.

A characteristic feature of the photoinduced effect in films at room temperature is that it depends strongly on the magnetic characteristics of the film employed. Specifically, the coercive force influences both the magnitude of the residual photoinduced magnetization and the minimum threshold light intensity at which the domain structure starts to change. We note that the effect described becomes stronger as the temperature of the film decreases to ~ 200 K. However, when the temperature decreases further, a strong uniaxial anisotropy, corresponding to spin-reorientation transitions, is induced in the film.

In view of the different character of the reorientation of the magnetic moment vector from its initial position into the opposite position (and not from one easy-magnetization axis to another, as is observed in bulk crystals at cryogenic temperatures), the observed characteristics of the change in the domain structure do not fit within the standard notions of the reorientation of the magnetization vector under the action of the photoinduced magnetic anisotropy. Considering the deformation recorded in Ref. 3 of single crystals under the action of polarized light at 4 K and the magnetization reversal observed in our films under the action of mechanical stresses applied along both easy-magnetization axes, it can be assumed that the magnetostriction mechanism plays a large role in the appearance of the described effect and the change in the magnetization of the film (and the corresponding magnetic domains) can be attributed to the photoinduced deformation of the film along the corresponding axis. This is also confirmed by the absence of the effect in other similar films which differ only in that their magnetostriction constants are lower. On the whole, however, in our opinion, this effect can be explained on the basis of a model based on the effect of photosensitive, magnetically anisotropic centers on the magnetic characteristics of the material. The assumption that nontrivalent impurities are present in the experimental iron garnet films is correct, because PbO-based fluxes were used in the process of the epitaxy of the films. Irradiation of a film with polarized light induces charge transfer between the impurity centers and defects. The character of this exchange depends on, specifically, the polarization of the light and the exchange leads to a deformation of the crystal lattice and a change of its magnetoelastic energy, which affects the domain structure. Photoinduced magnetic anisotropy along the corresponding easy-magnetization axis can occur at the same time.

To determine the possible thermal mechanism of the action of light on the domain structure, we examined the change in the domain structure at different intensities of the irradiating light, using intermittent illumination. For high intensity of the radiation heating the film, the manner in which the domain structure changes is altered slightly primarily in the direction of a weaker polarization dependence. At the same time, for radiation power densities below ~ 1 W/cm^2 the unique polarization dependence of the effect, when additional magnetization is unnecessary and the absorption of 0.63 μm radiation by the film is very weak, makes it possible to attribute the observed change in the domain structure and magnetization of the film to polarization-dependent photoinduced effects.

[1] V. F. Kovalenko, P. S. Kuts, and V. P. Sokhatskiĭ, Fiz. Tverd. Tela (Leningrad) **24**, 145 (1982) [Sov. Phys. Solid State **24**, 80 (1982)].
[2] A. B. Chishik, A. Masiewski, and A. Stupakiewicz in *14th International Colloquium on Magnetic Films and Surfaces*, Dusseldorf, 1994, p. 786.
[3] J. F. Dillon, E. M. Gyorgy, and J. P. Remeika, Appl. Phys. Lett. **15**, 221 (1969).

Translated by M. E. Alferieff