Photoinduced change in magnetostriction in yttrium iron garnet

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A change in the magnetostriction of $Y_3Fe_5O_{12}$ has been observed after the application of light. A large photoinduced effect is observed on both the plot of the magnetostrictive strain λ against the field and the plot of the saturation magnetostriction against the orientation of the magnetization.

Magnetoelastic effects may play a governing role in the appearance and relaxation of a photoinduced magnetic or optical anisotropy in photomagnetic $Y_3Fe_5O_{12}$ single crystals.

In this letter we report preliminary results of experiments on the effect of illumination on the linear magnetostriction of photomagnetic $Y_3Fe_5O_{12}$ single crystals grown from a $BaO\text{-}B_2O_3$ solvent.[1] The test samples are (110) disks ~6 mm in diameter and up to 1 mm thick, with polished and chemically etched surfaces. The strain during the magnetostriction is measured with chromium strain gauges fabricated directly on the test disks. After layer of chromium is deposited on the surface of the disk in a vacuum, a strain gauge is formed along the $[\bar{1}11]$ direction by photolithography. The strain gauges have a resistance in the range 0.5–4.0 kΩ and a strain sensitivity close to 2. The sample is kept in contact with the heat sink by a paste which causes no strain during the cooling. The change in the resistance of the strain gauge during the magnetostrictive deformation is measured by a bridge circuit, from which the output

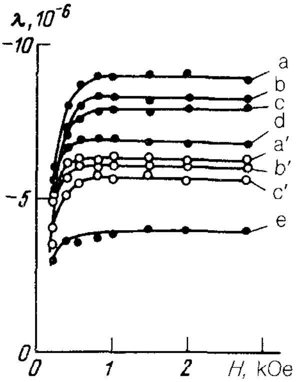

FIG. 1. Field dependence of the magnetostrictive strain λ measured (a–e) before and (a'–c') after the application of light at various temperatures: a,a'—100 K; b,b'—110 K; c,c'—135 K; d—155 K; 3—300 K.

signal is sent to a chart recorder. This apparatus is capable of measuring magnetostrictive strains $\lambda \sim 10^{-6}$. The cryostat design allows the state of the domain structure to be monitored on the basis of Faraday effect in IR light. We studied the field dependence of the magnetostrictive strain λ in the $[\bar{1}11]$ direction in static fields up to 3 kOe over the temperature range 100–300 K before and after the application of the light. Curves of the saturation magnetization $\lambda - \lambda_\varphi$ along the $[\bar{1}11]$ direction verus the orientation of the magnetization in the (110) plane are recorded by rotating an electromagnet away from the $[\bar{1}11]$ axis. Light of intensity ~ 10 mW/cm^2 from an incandescent lamp is applied for 15 min.

Figure 1 shows the field dependence of the magnetostrictive strain λ measured at various temperatures before and after the application of the light. At 100 K, there is a large photoinduced decrease in the magnetostriction λ. With increasing temperature, the photoinduced change in the magnetostriction, $\Delta\lambda = \lambda^T - \lambda^C$, decreases significantly; above ~ 150 K, the change is no longer observed under our experimental conditions. We should point out that the positive magnetostrictive strain λ, which is observed in the $[111]$ direction before the illumination when the magnetic field is oriented perpendicular to the plane of the disk, increases after the light is applied. In addition, a positive change in the magnetostriction λ is observed after the application of the light in the case of magnetization in the plane of the disk perpendicular to the strain gauge.

Figure 2 shows the saturation magnetization $\lambda - \lambda_\varphi$ along the $[\bar{1}11]$ direction versus the orientation of the magnetic field in the (110) plane, measured before and after illumination at 100 K. We see an unusual angular dependence, with a maximum in the magnetostrictive strain λ in the $[\bar{1}11]$ direction in the case of magnetization along the $[\bar{1}11]$ direction. The observed photoinduced change in the magnetostriction in a state of magnetic saturation is substantial.

The magnetooptic measurements reveal a Faraday domain structure in the (110) disks. We observe no photoinduced changes in this domain structure. Therefore, the photoinduced changes in the field dependence of the magnetostriction cannot be explained on the basis of changes in the initial state of the domain structure. The photoinduced changes observed in the magnetostriction in the state of magnetic saturation

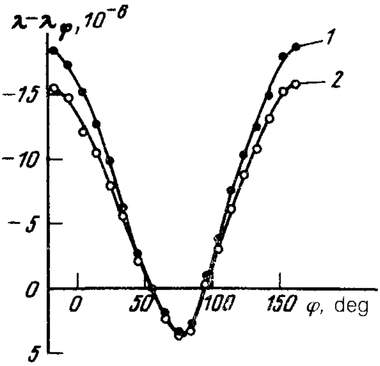

FIG. 2. Angular dependence of the saturation magnetostriction $\lambda - \lambda_\varphi$ in the $[\bar{1}11]$ direction versus the orientation of the magnetic field in the (110) plane. 1—Before; 2—after the application of the light. The angle φ is reckoned from the [001] axis. The magnetic field is 3 kOe.

and also in the field dependence of λ can be explained in terms of the appearance, as a result of the application of the light, of anisotropic centers which change the elastic and magnetoelastic properties of the samples. The observed angular dependence of the saturation magnetostriction is evidently related to the induced perpendicular anisotropy, according to the Faraday domain structure in the samples. For the (110) plane, the induced perpendicular anisotropy is orthorhombic, not uniaxial. If the induced anisotropy is of a magnetoelastic nature, and anisotropy of the elastic stress arises in the (110) plane. Taking into account the elastic stress, which depends on the magnetization direction, and which has the nonvanishing components $\sigma_{22} = \sigma_{33} = \sigma_{23} = 1/2\sigma \sin^2 \varphi$, we can write the angular dependence of the magnetostriction $\lambda - \lambda_\varphi$ in the $[\bar{1}11]$ direction as a function of the orientation of the magnetic field H in the $(\bar{1}10)$ plane as follows, within terms of second order in the magnetization:

$$\lambda - \lambda_\varphi = \lambda_\sigma\left(\frac{2}{3} - \sin^2\varphi\right) + \lambda_{111}\left(1 - \frac{\sqrt{2}}{2}\sin 2\varphi - \frac{1}{2}\sin^2\varphi\right) ,$$

where $\lambda_\sigma = \sigma/3(1/c_{11} - c_{12} + 1/2c_{44})$, σ is the compressional elastic stress perpendicular to the $(\bar{1}10)$ plane, and c_{11}, c_{12}, and c_{44} are elastic moduli. The experimental and calculated curves of $\lambda - \lambda_\varphi$ agree well with the following parameter values: $\lambda^T_{111} = -0.73\times 10^{-5}, \lambda^T_\sigma = -1.42\times 10^{-5}$ before the application of the light and $\lambda^C_{111} = -0.63\times 10^{-5}, \lambda^C_\sigma = -1.17\times 10^{-5}$ after. The values of the constants λ_σ and λ_{111} are changed slightly when we allow for the experimental errors, but the sign and order of magnitude of the photoinduced changes always remain the same: $\Delta\lambda_\sigma = \lambda^T_\sigma - \lambda^C_\sigma$ and $\Delta\lambda_{111} = \lambda^T_{111} - \lambda^C_{111}$.

In summary, unpolarized light causes a decrease in the magnetostriction constants λ_{111} and λ_σ, accompanied by a change in the elastic state of the sample. Photoinduced changes in the field dependence of the magnetostriction in the yttrium iron garnet single crystals studied also result from changes in the magnetostriction constants. These results provide evidence for a magnetoelastic nature of the photoinduced anisotropic centers in $Y_3Fe_5O_{12}$.

[1]V. A. Timofeeva, Rost kristallov iz rastvorov-rasplavov (Crystal Growth from Molten Solutions), Nauka, Moscow, 1978.

Translated by Dave Parsons