Photoinduced polarization-dependent changes in the anisotropy in ferrimagnetic $(YCa)_3(FeCoGe)_5O_{12}$ films

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A photoinduced increase of 1-2 G in the perpendicular component of the magnetization has been observed in a ferrimagnetic $(YCa)_3(FeCoGe)_5O_{12}$ film. The light pulses had $\lambda=0.53$ μm and $t=20$ ns. The corresponding change in the anisotropy energy is 10^4 erg/cm^3.

Photoinduced effects of two types occur in magnetic materials: (1) effects which do not depend on the polarization of the optical radiation (these effects are observed in a wide range of magnetic materials — doped chromospinels and ferrospinels and iron garnets[1]) and (2) effects which are sensitive to the polarization [such effects have previously been observed only in silicon-doped yttrium iron garnet (YIG)].

In this letter we are reporting the observation of a polarization-dependent change in the perpendicular component of the magnetization in ferrimagnetic garnet films with the composition $Y_2Ca_1Fe_{3.9}Co_{0.1}Ge_1O_{12}$. The magnitude of this magnetization component is determined by the magnetic-anisotropy energy of the sample. The magnetic properties of these films ($m \sim 10$ G, $K\sim -10^4$ erg/cm^3 at $T=290$ K) were reported in Refs. 2 and 3. For the measurements, disks 1.8 mm in diameter were cut from films 7–10 μm thick grown in the (001) plane on gallium–gadolinium garnet substrates. The test sample was on a quartz shaft which could rotate the sample with respect to the external magnetic field, which was applied in the plane of the disk. The light source was a pulsed neodymium laser (we used the second harmonic) with a wavelength of 0.532 μm and a pulse length $\tau = 20$ ns. The energy density incident normally on the plane of the sample did not exceed 0.04 J/cm^2. The pulse repetition frequency of the light was 12 Hz. The change in magnetization was detected by a measurement coil beside the sample .[4] The axis of this coil lay in the plane of the sample. When the axis of the measurement coil was aligned perpendicular to the magnetic field, we detected changes in the perpendicular component of the magnetization. When the sample was illuminated, an emf arose in the coil because of the change in magnetic flux. The amplitude of this emf was proportional to the rate of change of the magnetic flux. The emf pulse was recorded on a chart recorder with the help of a boxcar integrator.

The emf pulses observed across the measurement coil were unipolar, reproducing the shape of the laser pulse almost perfectly. The pulses are unipolar because the time scales for the relaxation of the magnetization to its "dark" value are long (in comparison with light pulses). Figure 1 shows the angular distribution of the photoinduced increase in the perpendicular component of the magnetization for various polarizations of the light at $T=78$ K. The shape of these curves indicates that the

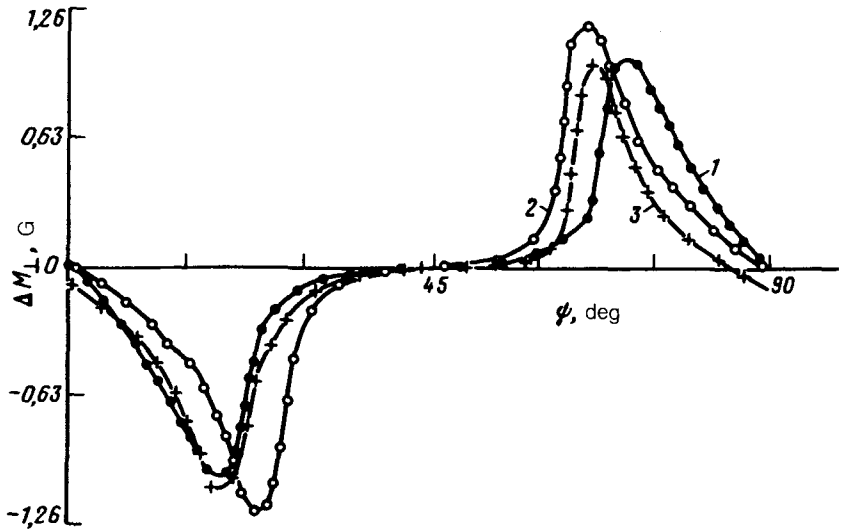

FIG. 1. Photoinduced change in the perpendicular component of the magnetization as a function of the angle (ψ) between the magnetic field H and the [100] axis (T = 77 K, H = 5 kOe). *1*—The polarization of the light is in the orientation **E**⊥ **H**, *2*—**E**||**H**; *3*—**E** makes an angle of 45° with **H**.

cubic-anisotropy energy increases upon the application of polarized light, and a uniaxial anisotropy arises along the polarization plane of the light. The amplitude of the photoinduced change in the magnetization falls off rapidly to zero as the temperature is raised to 180 K.

Figure 2 shows the photoinduced change in the perpendicular component of the magnetization as a function of the magnitude of the external field H for various polarizations of the light. The observed hysteresis is due to a photoinduced uniaxial anisotropy along the polarization plane. Part of the photoinduced anisotropy has a decay time on the order of a few tens of seconds. The largest changes in the perpendicular component of the magnetization in a field H = 5 kOe were ~1–2 G; these figures correspond to a change $\sim 10^4$ erg/cm^3 in the cubic-magnetic-anisotropy energy.

In interpreting this effect we start from the position that, as the optical radiation acts on the impurity electronic subsystem of the crystal, it can alter the nature of the exchange and relativistic interactions in the magnetic subsystem. The latter interactions are known to be responsible for the large photomagnetic effects in doped YIG .[1] The nature of the effect in these films is related to the presence of highly anisotropic and photosensitive cobalt ions. This circumstance is an argument in favor of a relativistic mechanism, as is the dependence of the effect on the orientation of the linear polarization of the light. Furthermore, a large magnetic aftereffect due to the induction of a uniaxial anisotropy has been observed in these films .[2,5] Accordingly, ignoring the changes in the exchange interactions, we interpret the effect as a rotation of the

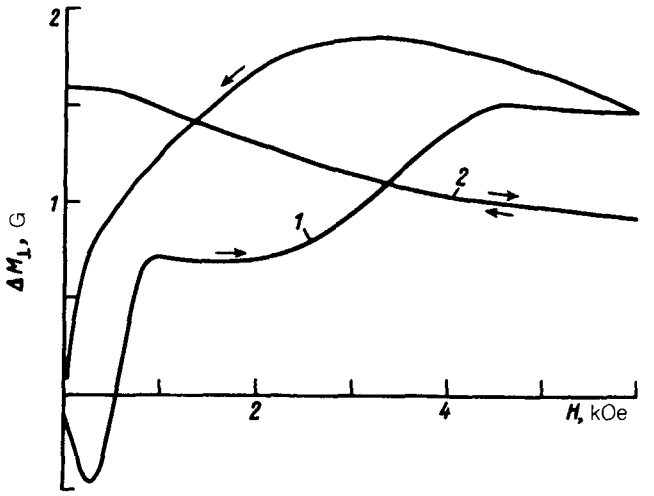

FIG. 2. Photoinduced change in the perpendicular component of the magnetization versus the magnitude of the external magnetic field, $H(\psi \approx 12°, T = 77$ K). *1*—The polarization of the light is in the orientation **E**⊥ **H**; *2*—**E**∥**H**.

magnetization vector M caused by a photoinduced change in anisotropy. Below we work from this effect to generate a phenomenological description of the effect, based solely on symmetry considerations.

We start from the standard formula for the magnetic energy of a film in a single-domain state:

$$W(\mathbf{m}) = (1/2)K_u m_z^2 + K_1(m_x^2 m_y^2 + m_y^2 m_z^2 + m_x^2 m_z^2) + K_2 m_x^2 m_y^2 m_z^2 + k_{ij} m_i m_j - \mathbf{M}\cdot\mathbf{H}. \tag{1}$$

Here K_u and K_1, K_2 are the constants of the uniaxial (growth) and cubic anisotropies, H is the magnetic field, and $\mathbf{m} = \mathbf{M}/|\mathbf{M}|$. The tensor components k_{ij} describe the second-order photoinduced magnetic anisotropy. They depend on the magnetization $\mathbf{m}$ and on the orientation of the linear-polarization vector $\mathbf{e}$ of the light ($|\mathbf{e}| = 1$) during the illumination. If the sample is illuminated for a time long enough that a steady state $\mathbf{m}'$ is reached (this situation occurred experimentally), we can expand $k_{ij}(\mathbf{m}', \mathbf{e})$ in components of $\mathbf{m}'$ and $\mathbf{e}$:

$$k_{ij}(e,\ m') = \lambda_{ijkn} m'_k m'_n + \nu_{ijkn} e_k e_n. \tag{2}$$

By virtue of the cubic symmetry of a garnet, the tensors $\hat{\lambda}$ and $\hat{\nu}$ are described by the four constants[6] $\lambda_{xxxx} = F, \lambda_{xyxy} = G, \nu_{xxxx} = A, \nu_{xyxy} =$ B. Under the experimental conditions, m' is the same as m at the measurement time. In this case, we can easily verify, by substituting (2) into (1), that the constants F and G lead to simply a change in K_1, while the induced uniaxial anisotropy is determined exclusively by the second term in (2). By minimizing the energy in (1) we can then determine the equilibrium orientation of $m^{(i)}$ before the illumination (for $k_{ij} = 0$) and the steady-state orientation

of the magnetization $m^{(f)}$ during illumination ($k_{ij} \neq 0$). Furthermore, we can determine the renormalized constants $K_1' = K_1 + \delta K$, where δK is the magnitude of the photoinduced change in K_1. We can then work from the formula

$$\Delta M_\perp(\psi) = |\mathbf{M}|[(m_y^{(f)} - m_y^{(i)})\cos\psi - (m_x^{(f)} - m_x^{(i)})\sin\psi] \quad (3)$$

to calculate the observable quantity $\Delta M_\perp$. A satisfactory agreement between theory and experiment is reached with the following values of the adjustable parameters (in units of $|K_1|$): $A < 0$, $B > 0$, $\delta K_1 = -1$, $|B/A| \approx 5$. The most likely microscopic mechanism is an optical charge exchange $Co^{3+} \rightarrow Co^{2+}$ of cobalt ions which are localized in different, orientationally nonequivalent crystallographic sites and which have a stable valence in the YIG lattice.[7] The polarization-independent component of δK_1 can be attributed to an increase in the number of highly anisotropic Co^{2+} ions in octahedral sites. The polarization-dependent component can be explained by the standard model of four types of octahedral sites with local [111] axes. In that model, there is a predominant filling of one site because of the anisotropy of the photoabsorption; as a result, a macroscopic anisotropy arises. Under the conditions $A < 0$, $B > 0$, the maximum filling of a specific site occurs when the polarization plane of the light is orthogonal with respect to the local axis of the site.

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