Photomagnetization of iron borate

M. Borovets, A. A. Garmonov, S. G. Rudov, and Yu. M. Fedorov
Institute of General Physics, Academy of Sciences of the USSR

(Submitted 23 October 1989)
Pis'ma Zh. Eksp. Teor. Fiz. **50**, No. 10, 431–433 (25 November 1989)

During pulsed photoexcitation of iron borate samples, the absolute value of the ferromagnetism vector increases, and the equilibrium orientation of this vector in the external magnetic field changes by an angle on the order of a few degrees.

Antiferromagnetic insulators can be magnetized through a selective photoexcitation of magnetically active ions of one of the sublattices. The degeneracy between the sublattices is lifted either by a stress field[1] or by a magnetic field near the magnetic phase transition.[2] The same result can be achieved by using polarized light, by virture of linear dichroism.[1] In antiferromagnets with a slight ferromagnetism, the presence of a ferromagnetic moment is a consequence of the anisotropic Dzyaloshinskiĭ–Mori interaction, which is very sensitive to the electronic configuration of the magnetically active ion. For this reason, even if the probabilities for the photoexcitation of the sublattice ions are equal, one would expect changes in the ferromagnetism vector, in both magnitude and direction, because of the changes in the effective anisotropy fields at the photoexcited ions, which are exchange-intensified in these materials.[3]

For the experiments we used nominally pure $FeBO_3$ samples which were prepared as disks in the (111) basal plane, with dimensions of 1.5 mm (the diameter) $\times$ 0.05 mm. As the excitation source we used a parametric light source pumped by the second harmonic from a neodymium laser. The pulse length of this light source was 15–20 ns, the energy density of the light incident on the sample was 0.02 J/cm^2, the tuning interval was 0.7–2.7 μm, and the linewidth did not exceed 1 nm. In addition, we used the fundamental frequency and second harmonic of the neodymium laser ($\lambda = 1.06$ and 0.53 μm) and the beam from a nitrogen laser with $\lambda = 0.337$ μm. The samples were placed on the finger of a cryostat with an adjustable temperature, which was itself placed in the gap of an electromagnet, which produced a magnetic field up to 5 kOe in the (111) plane of the sample. The change in magnetic moment was detected as the voltage pulse which resulted from the change in the magnetic flux at a measurement coil wound around the sample (three to five turns). The magnitude of the photoinduced change in magnetization was proportional to the area under the voltage pulse. We detected changes in both the longitudinal and transverse (with respect to the external magnetic field) components of the ferromagnetism vector **m**.

Figure 1(a) shows the shape of the oscilloscope traces of the signal from the measurement coil. The sign of the signal is the same as that of the change in the components of the ferromagnetism vector. When the samples were exposed to light in the wavelength interval 0.75–1.02 μm in external fields above 30 Oe (a single-domain sample) at $T = 78$ K, we observed a signal corresponding to an increase in the longitudinal component of the magnetization. This signal was not present when we used the wavelengths $\lambda = 0.337$ and 1.06 μm; it was negligibly low in the case $\lambda = 0.53$ μm.

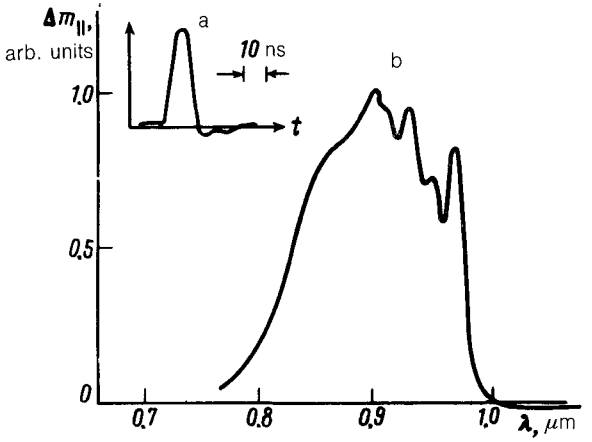

FIG. 1. a—Oscilloscope trace of the signal from the measurement coil ($\lambda = 0.97$ μm); b—spectrum of $\Delta m_{\parallel}$ ($T = 78$ K, $H = 250$ Oe).

Figure 1(b) shows the magnetization response to photoexcitation by light with various wavelengths and a constant intensity. This behavior reflects the fine structure of the ${}^6A_{1g} - {}^4T_{1g}$ transition.[4] In weak magnetic fields, below 50 Oe, the signal whose duration is the same as that of the photoexcitation pulse is accompanied by damped voltage oscillations, which rapidly disappear as the magnetic field is strengthened. The magnitude and period of these oscillations increase with increasing thickness of the sample. Signals of this nature were observed over a broad wavelength range (0.337–2 μm) and are apparently due to magnetoacoustic oscillations which arise during the pulsed heating of the surface of the sample. We will restrict the discussion below to the unipolar, nonoscillating signal, which corresponds to an increase in the longitudinal component of the magnetization and a corresponding decrease in the transverse component. Figure 2 shows the field dependence of these signals. The magnitudes of the photoinduced changes in the components of the ferromagnetism vector, $\Delta m_{\parallel}$ and $\Delta m_{\perp}$, increase linearly with the external magnetic field H in weak fields, go through a maximum, and

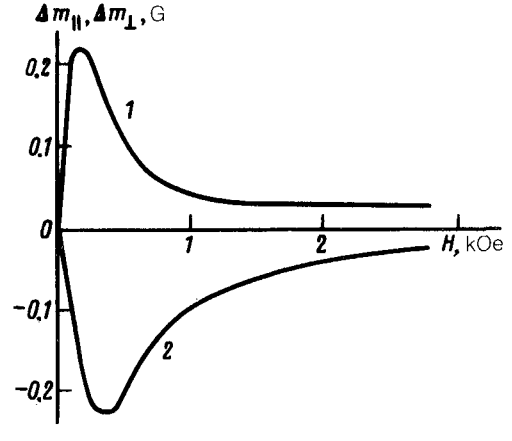

FIG. 2. Field dependence of (1) $\Delta m_{\parallel}$ and (2) $\Delta m_{\perp}$ ($T = 78$ K, $\lambda = 0.97$ μm, $\phi = 15° \pm 5°$).

then fall off as $1/H^2$ and $1/H$, respectively. In fields above 2 kOe, $\Delta m_{\parallel}$ does not depend on the field strength. At $H = 250$ Oe, in the temperature range 78–200 K, $\Delta m_{\parallel}$ and $\Delta m_{\perp}$ decrease monotonically to zero. At $H > 2$ kOe, $\Delta m_{\parallel}$ varies only slightly with the temperature, in the manner of the magnetization of this compound. The observed field and temperature dependence of $\Delta m_{\parallel}$ and $\Delta m_{\perp}$ can be explained on the basis of an increase in the absolute value of **m** and a change in its equilibrium orientation by an angle of a few degrees (according to an estimate).

Let us analyze the experimental results in the continuum approximation, assuming that the sample is uniformly magnetized. Minimizing the free energy $E = E_0 + Am^2/2 - Dm(M^2 - m^2/4)^{1/2} + K\sin^2 3(\phi + \alpha) - Hm\cos\alpha$ with respect to m (the absolute value of the ferromagnetism vector) and with respect to α (the angle between H and m), we find the following equilibrium values of these properties in a first approximation:

$$m_{\parallel} = m\cos\alpha;\quad m_{\perp} = m\sin\alpha;\quad m \approx DM/A \approx 10\ \text{G};$$

$$\alpha \approx (-3K\sin 6\phi)/(Hm + 18K\cos 6\phi);\quad |\alpha| \ll 1,$$

where $K \sim 10^2$ erg/cm^3 is the energy of the effective in-plane anisotropy, ϕ is the angle between **H** and the easy axis of this anisotropy, M is the magnetization of the sublattices, A is the antiferromagnetic exchange constant, and D is the constant of the Dzyaloshinskiĭ interaction.

Under the assumption that the observed changes in the components of the ferromagnetism vector are related to changes in K and D, we can derive expressions for the changes in $m_{\parallel}$ and $m_{\perp}$:

$$\Delta m_{\parallel} \approx \Delta DM/A - \Delta K(9KHm^2\sin^2 6\phi)/(Hm + 18K\cos 6\phi)^3$$

$$\Delta m_{\perp} \approx -\Delta K(3Hm^2\sin 6\phi)/(Hm + 18K\cos 6\phi)^2.$$

These expressions give a satisfactory description of the experimental field dependence at $\Delta K < 0$ and $\Delta D > 0$. This result suggests that the photoexcitation of the magnetic ions leads to a cancellation of the original in-plane anisotropy. We believe that the increase in the absolute value of the ferromagnetism vector is a consequence of an increase in the constant D (by an amount on the order of 0.2% on the average over the entire sample volume), which is in turn caused by the appearance of an orbital angular momentum at the photoexcited iron ions.

We wish to thank V. G. Veselago for support of this study.

[1]I. Hdzrichter *et al.*, Phys. Rev. Lett. **26**, 652 (1971).
[2]V. V. Eremenko *et al.*, Zh. Eksp. Teor. Fiz. **84**, 2251 (1983) [Sov. Phys. JETP **57**, 1312 (1983)].
[3]V. I. Ozhogin and V. L. Preobrazhenskiĭ, Usp. Fiz. Nauk **155**, 593 (1988) [Sov. Phys. Usp. **31**, 713 (1988)].
[4]B. Andlauer *et al.*, Solid State Commun. **13**, 1655 (1973).

Translated by Dave Parsons