Polarization-dependent photoinduced changes in magnetic-resonance parameters in α-Fe_2O_3:Ga,Yb

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Photoinduced changes in magnetic properties have been observed in weakly ferromagnetic crystals of hematite doped with ytterbium ions. Changes in both the magnitude of the resonant field and the width of the antiferromagnetic-resonance line are observed at $T<130$ K, depending on the polarization of the light. The effect is attributed to a photoinduced conversion of a center containing an ytterbium ion. © *1995 American Institute of Physics.*

The known photomagnetics in which rare-earth ions are responsible for photoinduced changes in magnetic properties are distinguished by a diversity of observable photomagnetic effects.[1–3] All these effects are governed by the individual electronic structures of the rare-earth ions, and they occur at low temperatures. It is important to expand the temperature range in which a photomagnetic effect occurs because of possible practical applications and also to allow an experimental study of induced nonequilibrium states in magnetic materials. Creating a metastable photoinduced state at a high temperature (e.g., above the boiling point of liquid nitrogen) differs from the situation at low temperatures in that it requires high potential barriers separating the different states and also in that the interaction of the photosensitive center with its magnetic surroundings must not be weak in comparison with thermal effects.

Doping hematite single crystals with rare-earth ions has resulted in the observation of some interesting anisotropic properties, which are associated with the effect of the competing anisotropies of the $3d$ and $4f$ subsystems. Crystals of α-Fe_2O_3:Eu exhibit a polarization-sensitive photomagnetic effect at temperatures $T<70$ K, at which illumination causes either the formation or disappearance (depending on the polarization of the light) of anisotropic magnetic centers containing europium ions.[4]

In this letter we are reporting the observation of changes in magnetic-resonance parameters in weakly ferromagnetic crystals of α-Fe_2O_3:Yb(0.005 at. %), Ga(5 at. %) upon illumination with polarized light at temperatures $T\leqslant 130$ K.

The experimental arrangement is described in Ref. 4. As before, the gallium ions are added to broaden the temperature range in which the weakly ferromagnetic phase exists.

We first note that these crystals differ from crystals doped with europium ions in that they exhibit a pronounced anisotropy of the resonant field (H_r). At liquid-nitrogen temperatures, this anisotropy is strictly hexagonal and amounts to about 1 kOe. This figure is comparable to data on crystals doped with cobalt ions,[5] but at cobalt-ion concentrations more than an order of magnitude above the concentration of ytterbium ions. As the

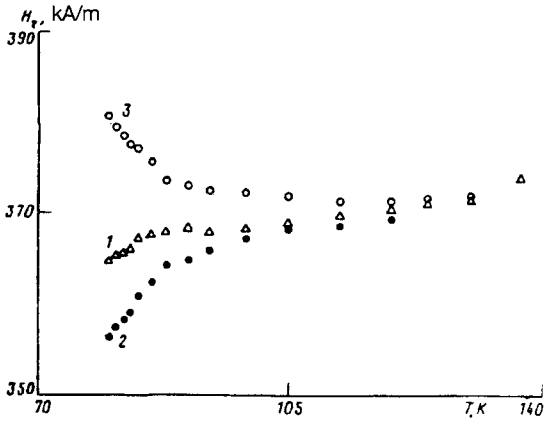

FIG. 1. Temperature dependence of the resonant field. 1—Original sample; 2, 3—illumination in the configurations $\bar{E}\|\bar{H}_r$ and $\bar{E}\perp\bar{H}_r$, respectively. The direction of the magnetic field in the basal plane corresponds to an angle $\varphi_n = 15°$, measured from the easy-magnetization axis.

temperature is lowered from room temperature to liquid-nitrogen temperature, the intensity of the signal falls off by a factor of five. This decrease may be evidence of a decrease in the component of the magnetic moment in the basal plane of the crystal due to an excursion of the moment to the plane.

The reaction of the crystal to the illumination with polarized light is also different from what has been observed previously.[4] In the case at hand, the resonant field either increases ($\bar{E}\perp\bar{H}$) or decreases ($\bar{E}\|\bar{H}$), depending on the polarization of the light (Fig. 1). For a fixed polarization angle θ, the sign of the shift (δH_r) of the resonant field is independent of the direction of the external magnetic field in the basal plane of the crystal (i.e., independent of the angle φ). The state created as the result of the illumination (curve 2 or 3 in Fig. 1) is at dynamic equilibrium with the field of the electromagnetic radiation. After the light is turned off, regardless of the polarization of the exciting light, there is a relaxation to the original state (curve 1 in Fig. 1). Over the temperature range from 80 to 130 K, there is a slight residual shift of the resonant field (which amounts to less than 5% of the maximum value). On a plot of the shift δH_r versus the optical power P during illumination with white light, we observe the onset of saturation at $P \geqslant 60$ mW/cm^2. The time for the onset of this saturation depends on both the optical power and the measurement temperature. The onset of a photomagnetic effect as we move away from high temperatures correlates with the significant increase in the magnetic crystallographic anisotropy in the basal plane.

Figure 2 shows the magnetic-resonance parameters versus the polarization angle of the light. This shift of the resonant field can be described by the empirical formula

$$\delta H_r(\varphi,T,P) = A(\varphi,T,P) - B(\varphi,T,P)\cos^2\theta, \tag{1}$$

where the extreme values of δH_r are determined in terms of A and B. Note that there exists an angle $\theta_0 \neq 0$ at which we have $\delta H_r = 0$ and at which the system "does not feel" the light. A new result is a dependence of the width (ΔH_{pp}) of the magnetic-resonance line on the polarization of the light. The minimum value of ΔH_{pp} is exhibited by a crystal which has not been illuminated. During illumination, the minimum of ΔH_{pp} correspond to the value θ_0, at which we have $\delta H_r = 0$.

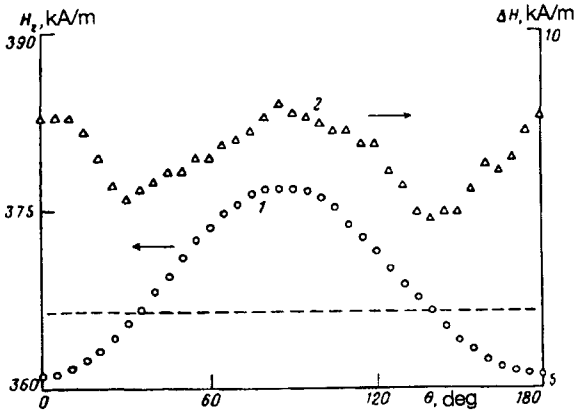

FIG. 2. Parameters of the magnetic resonance versus the light polarization angle. 1—Resonant field; 2—linewidth. The horizontal dashed line shows the resonant field of a sample which has not been illuminated. $\varphi_n = 15°$, $T = 85$ K.

Since the divalent iron ions do not give rise to any low-temperature features in the magnetic-resonance parameters, we assume that the oxygen deficiency is offset in this case by the formation of Yb^{2+} ions. The divalent ytterbium ion has a filled $4f$ electron shell and a zero magnetic moment. It is possible that, during illumination, a photoelectron from a Yb^{2+} ion enters the field of an oxygen vacancy as a result of relaxation from an optically excited state and forms a highly anisotropic magnetic complex consisting of an ion of trivalent ytterbium to which an F center is bound. The photoinduced changes in the magnetic system which are detected are the result of the joint effects of different, apparently competing, complexes in nonequivalent crystallographic positions. The probability for the formation of a magnetic complex of this sort is determined by the probability for a transition of a photoelectron to a optically excited level. That probability depends on the polarization of the light, more specifically, on the angle between the vector $\vec{E}$ of the light wave and the local quantization axis (Z axis) of the photocenter. In this case we would see why the fields which arise from centers in different positions might cancel each other out at a certain value of the polarization angle.

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[1] E. I. Golovenchits and V. A. Sanina, Zh. Eksp. Teor. Fiz. **80**, 1911 (1981) [Sov. Phys. JETP **53**, 992 (1981)].
[2] S. Kurita *et al.*, J. Phys. Soc. Jpn. **56**, 612 (1987).
[3] G. A. Petrakovskiĭ and G. S. Patrin, Zh. Eksp. Teor. Fiz. **90**, 1769 (1986) [Sov. Phys. JETP **63**, 1038 (1986)].
[4] G. S. Patrin *et al.*, Zh. Eksp. Teor. Fiz. **101**, 635 (1992) [Sov. Phys. JETP **74**, 337 (1992)].
[5] G. A. Petrakovskiĭ *et al.*, Zh. Eksp. Teor. Fiz. **85**, 691 (1983) [Sov. Phys. JETP **58**, 403 (1983)].

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