WEB OF SCIENTIST: INTERNATIONAL SCIENTIFIC RESEARCH JOURNAL
ISSN: 2776-0979, Volume 3, Issue 9, Sep., 2022

TO THE MAGNETO-OPTICAL ANISOTROPY OF THE Mg CRYSTAL THE EFFECT OF CHANGING THE MAGNETIC STRUCTURE OF $FeBO_3$

Boydedayev Sobirjon Rahimjonovich,
Namangan Engineering and Construction Institute

Umaraliyev Maksud Mahmudovich,
Namangan Engineering and Construction Institute

Turgunov Adham Rakhmatillayevich
Namangan Engineering and Construction Institute
adxamturgunov2127@gmail.com

Abstract

The field dependence of the magnetic linear birefringence (MLB) in easyplane weak $FeBO_3$:Mg
ferromagnet has been investigated. It is found that MLB nonmonotonically (stepwise) tends to a constant
value with an increase in magnetic field at low temperatures. This feature of MLB in $FeBO_3$:Mg is related to the transformation of the crystal magnetic structure during magnetization.

INTRODUCTION

Optically transparent iron borate ($FeBO_3$) is a promising material for the element base of various magnetooptical devices. For this reason, the magnetic, optical, and magnetooptical properties of this easyplane weak ferromagnet had been intensively investigated and are known fairly well. However, a relatively short time ago, it was found [1, 2] that doping of $FeBO_3$ with diamagnetic Mg ions in low concentrations leads to a specific feature in the technical magnetization of $FeBO_3$ crystals: at low temperatures($T < Tc \approx 130$ K), with an external magnetic field H applied in the easymagnetization (111) plane, anincrease in H leads to the transformation of the magnetic structure of $FeBO_3$:Mg: it becomes spatially modulated rather than homogeneous. It was shown in [1–3] that the magnetic order of $FeBO_3$:Mg becomes modulated when the orientation of the vector **H** is close to one of three directions that are perpendicular to the directions of the twofold symmetry axes C_2 (near the directions of hard magnetization axes of in planehexagonal anisotropy). modulated magnetic structure (MMS) of the crystal exists in some temperature dependent range of magnetic field strengths and has the form of a static spin wave linearly polarized in the easymagnetization plane, in which the local antiferromagnetism vector oscillates near the axis $C_2 \perp \mathbf{H}$ when moving along the vector **H**.

EXPERIMENTAL

The experiments were performed on the same $FeBO_3$:Mg single crystal (Mg content ~ 0.1 wt %) that was used in the MMS studies in [1–3]. The sample was a planeparallel plate with transverse sizes of ~3 mm and thickness of ≈60 μm, with developed faces in the easymagnetization plane.

We analyzed the field dependence of the magnetic linear birefringence (MLB) in $FeBO_3$:Mg. As was noted above, MMS arises when a crystal is magnetized in the directions close to perpendiculars to the three C_2 axes; hence, the MLB dependence on H was investigated for the vector **H** oriented along the direction perpendicular to one of the C_2 axes and (for comparison) at $\mathbf{H} \parallel C_2$. To minimize the effect of magnetic linear dichroism on the measurement results, the MLB study was performed in the range of maximum optical transparency of iron borate, using argon laser radiation with the wavelength $\lambda \approx 0.514$ μm.

The MLB measurements were performed at temperatures from 80 to 295 K in a magnetic field of $H \leq 30$ Oe (in all experiments, the vector **H** was in the easymagnetization plane of the crystal), at normal incidence of light on the sample plane (light propagated in the crystal along the $C3$ axis, i.e., one of the three optical indicatrix axes); in this case, the plane of polarization of the incident light made an angle of π/4 with the **H** direction. The MLB value was determined from the phase shift between the normal modes as follows:

$$\alpha = 2\pi d(n_{||} - n_{\perp})/\lambda$$

(d is the sample thickness, $n_{||}$ and $n_{\perp}$ are the refractive indices for the light linearly polarized along and across the **H** direction, respectively) and measured with a phase compensator (λ/4 plate) according to the conventional technique based on modulation of the azimuth of the polarization plane of the light incident on the photodetector (FЙU_79) [5]. The photodetector signal was synchronously detected and applied at the Y input of an $X–Y$ recorder, with a signal proportional to H on the X input. The measured signal was recorded with linear magnetic field scan at a rate of ~1 Oe/s. The sensitivity of the experimental setup to the angle α was ≈0.001°; this value, recalculated to the difference $\Delta n = (n_{||} - n_{\perp})$ for the sample under study, corresponds to $\approx 3 \times 10^{-8}$.

WEB OF SCIENTIST: INTERNATIONAL SCIENTIFIC RESEARCH JOURNAL
ISSN: 2776-0979, Volume 3, Issue 9, Sep., 2022

RESULTS AND DISCUSSION

The studies performed showed that the dependence $\Delta n(H)$ barely changes with variations in the direction of the vector **H** in the (111) plane at temperatures above the temperature of crystal transition in the modulated magnetic state (i.e., at $T > Tc$). At the same time, at $T < Tc$, the dependences $\Delta n(H)$ observed at different magnetizing field orientations were radically different. As an example, the figure shows the field dependences of the MLB of the crystal studied, obtained at 80 and 150 K with the vector **H** oriented along one of the C_2 axes and perpendicular to this direction. A comparison of the plots shows that the curves $\Delta n(H)$ obtained at $T = 150$ K differ only slightly, whereas the dependences $\Delta n(H)$ measured at $T = 80$ K
significantly change with reorientation of **H**; specifically, the slope of the initial portion, magnetic hysteresis, and the saturation field change. The difference in the obtained curves $\Delta n(H)$ is especially pronounced in fairly strong magnetic fields. In particular, the figure indicates that, in contrast to the orientation **H** || C_2 (at
which Δn does not change within the experimental error with an increase in H at $H >$ 5 Oe), at **H** $\perp$ C_2, the $\Delta n(H)$ nonmonotonically (stepwise) tends to a constant value.
As was shown in [1], the MMS spatial period D in a $FeBO_3$:Mg crystal stepwise changes with a change in H. Comparing the plots in the figure, one can clearly
see a correlation between the position of steps in the curve $\Delta n(H)$ at **H** $\perp$ C_2 and the steps in the dependence $D(H)$ (the plot $D(H)$ at $T = 80$ K is taken from [1]). Let
us discuss this correlation in more detail, assuming that the observed features of the field dependence of MLB are related to the modulation of the crystal magnetic structure.

As was noted above, MMS arises when a crystal is magnetized in the easymagnetization plane along one of the hardmagnetization axes. Therefore, at **H** $\perp$ C_2, the magnetization tends to a constant value through rotation of the vector **m** toward the direction **H** (and, correspondingly, rotation of the vector **l** toward the direction of the C_2 axis, oriented perpendicularly to **H**). On the basis of the theoretical consideration [1] of the phase transition of the crystal from the homogeneous magnetic state to a spatially modulated one, the angle of deviation of the local vector **l** from the C_2 axis near the magnetic saturation fields in $FeBO_3$:Mg can be written as

$$\beta = 2[(A - mH - {2\pi^2\gamma}/{D^2}) / 3B]^{\frac{1}{2}} sin2\pi x / D = \beta_1 sin2\pi x / D, \quad (1)$$

where A, B, and γ are H independent constants, x is the current coordinate along the direction of the vector **H** (**H** $\perp$ C_2), and D is the spatial modulation period.

Note that, according to the data of [1–3], the angle β_1 is ~10° and decreases with an increase in *H*. With dueregard to the curve *D*(*H*) shown in the figure, expression (1) yields specifically the dependence β1(*H*).

Taking into account the dependence of MLB on the **l** orientation in the easymagnetization plane of $FeBO_3$:Mg [3, 4]

$$\Delta n \sim sin2(\theta - \beta)$$

(θ = π/4 is the azimuth of the polarization plane of the light incident on the crystal with respect to the direction of **H**), one can draw the following conclusion.

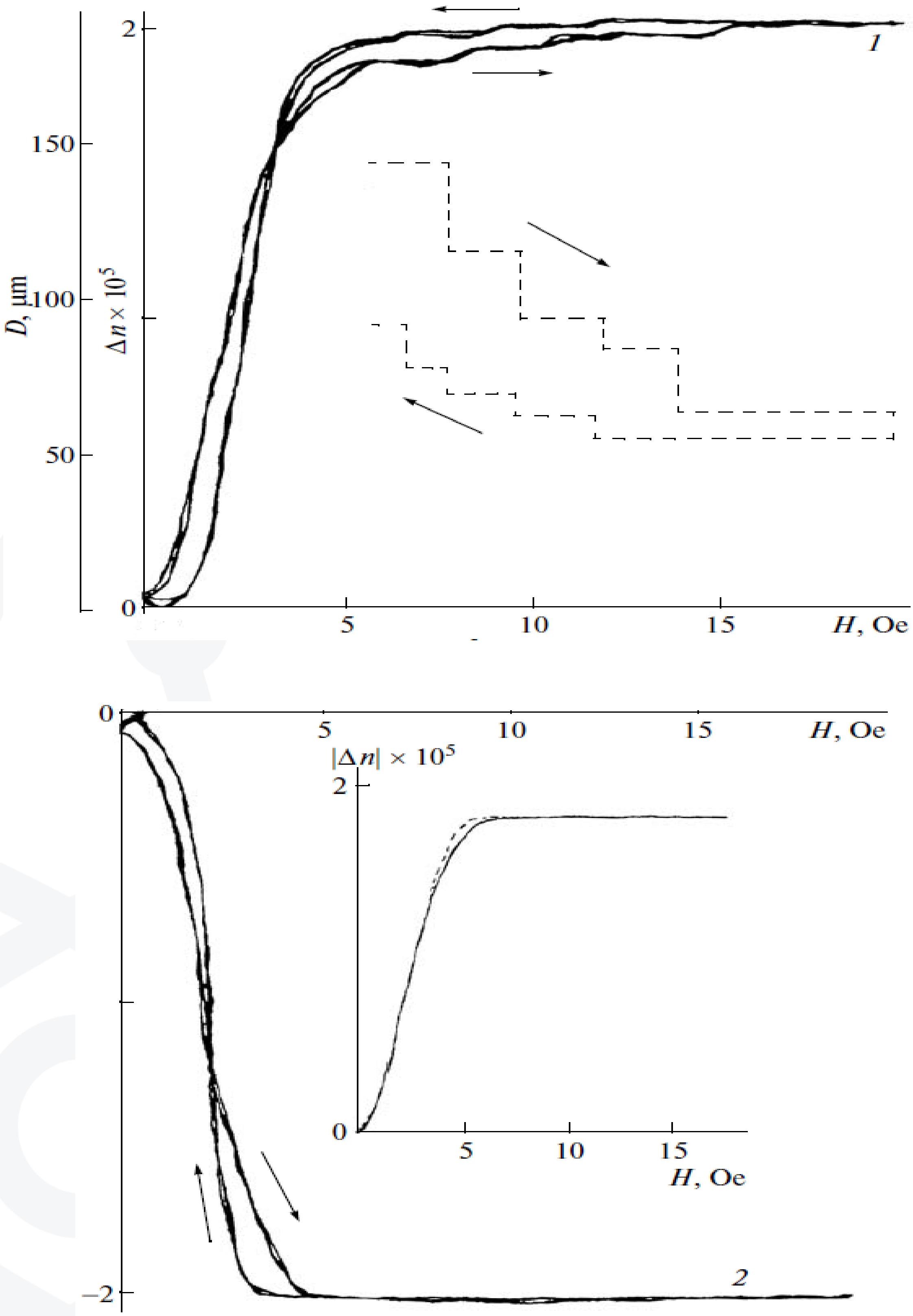
When the direction of the vector **l** in the modulated magnetic phase changes from point to point in the sample plane, the measurable α in the chosen geometry of the experiment is determined by the Δ*n* value averaged over the laser beam cross section. When the dependence of the angle β on *x* is described by (1), Δ*n* can be written as

$$\Delta n \sim r^{-1} \int_0^r \cos\left({}^{2\beta_1 sin\, 2\pi x}/_{D}\right) dx = r^{-1} \int_0^r [J_0\,(2\beta_1) + 2\sum_{k=1}^{n} J_{2k}(2\beta_1) cos4\pi kx\, / D]\, dx \approx J_0(2\beta_1) + J_2(2\beta_1) D sin({}^{4\pi r}/_{D})\, /\, 2\pi r, \quad (2)$$

where *r* is the sample linear size along the direction of **H** in the laser beam cross section and $J_0(2\beta_1)$ and $J_2(2\beta_1)$ are, respectively, the zero-and second-order Bessel functions [6].

For the experimentally observed values of β_1, $J_0\,(2\beta_1)$ »$J_2\,(2\beta_1)$ (for example, at β_1 = 10° $J_0(0.35)$ ≈0.96 and $J_2(0.35)$ ≈ 0.01 [6]) and the modulation period *D* « *r* (*r* ≈ 2 mm is the laser beam diameter). Hence, it follows from (2) that, in the modulated magnetic phase the field dependence of MLB is entirely determined by the dependence of the term $J_0(2\beta_1)$ on *H*. It can be seen from (1) that a step change in the modulation period leads to a step change in the angle β_1. Taking into account (2), this means that the steps observed in the dependence Δ*n*(*H*) at **H** ⊥ C_2 are due to the step change in β_1 in the magnetic field. According to the experimental results shown in the figure, the MMS period decreases with an increase in *H*. Moreover, at the same *H*, the *D* value measured in a field increasing from zero differs from that obtained in a field decreasing from maximum; therefore, according to (1) and (2), the steps in the curve Δ*n*(*H*) at **H** ⊥ C_2 are smaller at larger *H* and less pronounced in the reverse magnetization curve (figure).

WEB OF SCIENTIST: INTERNATIONAL SCIENTIFIC RESEARCH JOURNAL
ISSN: 2776-0979, Volume 3, Issue 9, Sep., 2022



WEB OF SCIENTIST: INTERNATIONAL SCIENTIFIC RESEARCH JOURNAL
ISSN: 2776-0979, Volume 3, Issue 9, Sep., 2022

Field dependences of the MLB in a $FeBO_3$:Mg crystal, obtained at T = 80 K for the magnetic field orientations (*1*) **H** ⊥ C_2 and (*2*) **H** || C_2. The dashed broken line is the field dependence of the spatial modulation period of the azimuth of the antiferromagnetism vector in the inhomogeneous magnetic phase of the crystal. The magnetic field scan direction is indicated by arrows. The inset shows the field dependences of the $FeBO_3$:Mg MLB crystal obtained at T = 150 K at magnetic field scanning from zero at **H** ⊥ C_2 (solid line) and **H** || C_2 (dashed line).

To conclude, we should note that no step change in the angle β_1 in a field H was found in [2]; therefore, the results of the MLB study performed here make it possible to refine the structure and reveal specific features of technical magnetization of the modulated magnetic phase of $FeBO_3$:Mg crystals.

REFERENCES

1. A.I.Mamadjanov, A.R.Turg'unov, M.M.Umaraliyev "INVESTIGATE THE DEPENDENCE OF THE LIGHT REFRACTIVE INDEX OF AN IDEAL GAS ON ITS PRESSURE USING INTERFEROMETRS" INTERNATIONAL JOURNAL OF ADVANCED RESEARCH ISSN:2320-5407 Article DOI: 10.21474/IJAR01/xxx
2. B. Yu. Sokolov, Fiz. Tverd. Tela (St. Petersburg) 47 (10), 1818 (2005) [Phys. Solid State 47, 1892 (2005)].
3. B. Yu. Sokolov, Fiz. Tverd. Tela (St. Petersburg) 47 (2), 252 (2005) [Phys. Solid State 47, 263 (2005)].
4. Yu. M. Fedorov, A. A. Leksikov, and A. E. Aksenov, Fiz.
5. Tverd. Tela (Leningrad) 26 (1), 220 (1984) [Sov. Phys. Solid State 26, 128 (1984)].
6. M. M. Chervinskii, S. F. Glagolev, and V. B. Arkhangel'skii, Methods and Tools for Measuring Magnetic Characteristics of Films (Йnergoatomizdat, Leningrad, 1990) [in Russian].
7. G. A. Korn and T. M. Korn, Mathematical Handbook for Scientists and Engineers (McGraw_Hill, New York.