Basal magnetic anisotropy of a weak ferromagnetic $FeBO_3$ crystal

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(Submitted 20 January 1979)

Pis'ma Zh. Eksp. Teor. Fiz. **29**, No. 5, 286–290 (5 March 1979)

The antiferromagnetic resonance method is used to measure the magnetic anisotropy in the basal plane of $FeBO_3$ crystals. The existence of a compensation temperature at which the hexagonal anisotropy constant changes sign is established. Temperature hysteresis of the resonant field is observed in the vicinity of compensation point.

PACS numbers: 75.30.Gw, 75.50.Dd, 75.60.Nt, 76.50. + g

The antiferromagnetic resonance (AFMR) method was used to investigate the hexagonal magnetic anisotropy of a weak rhombic ferromagnetic crystal $FeBO_3$ (space group symmetry D^6_{3d}) in the wavelength interval 8–30 mm and temperature region 1.5–300 K.[1] The anisotropy field was determined from displacement of the resonance line in the low-frequency branch of AFMR spectrum[1,2]

$$\left(\frac{\omega}{\gamma}\right)^2 = H\,(H + H_D) + H_{\Delta 1}^2 + 36\,H_E\,H_{eq}\cos 6\phi$$

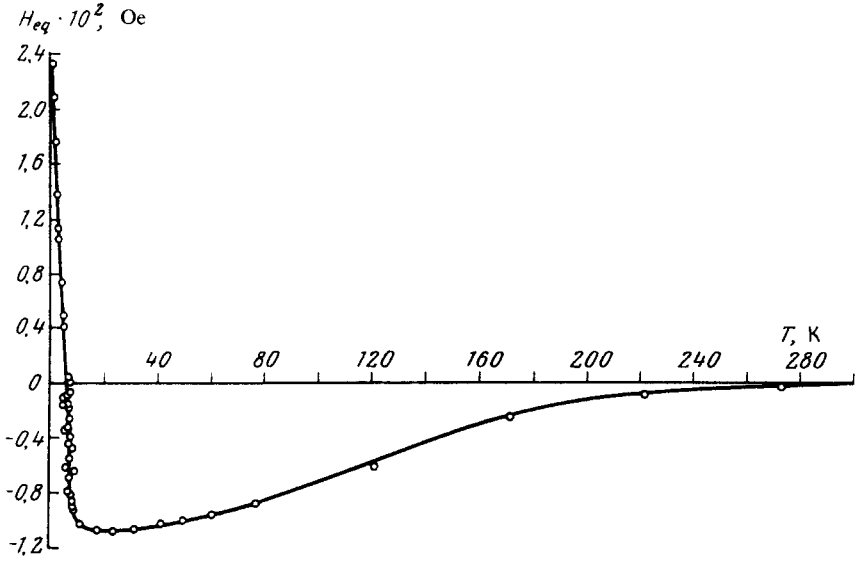

FIG. 1. Temperature dependence of hexagonal anisotropy field H_{eq} (crystal #1).

TABLE I.

# crystal	1	2	3	4	5	6
Method of growing	[7]			[3]		
$H_{eq} = 10^2$, Oe ($T = 4.2$ K)	0.7	1.6	1.7	3.7	—	—
$H_{eq} = 10^2$, Oe ($T = 77$ K)	−0.9	—	—	−0.7	−0.8	−0.7

in the course of rotating a constant magnetic field **H** in the basal plane of crystal.

In the above expression $\gamma = ge/2mc$ in the gyromagnetic ratio, H_D is the Dzyaloshinskiĭ field, $H^2_{\Delta 1}$ and 36 $H_E H_{eq}$ are isotropic and anisotropic energy gaps, respectively, H_E is exchange field, H_{eq} is hexagonal anisotropy field in the (111) plane, and ϕ is angle between the external magnetic field and one of the crystal symmetry planes. Effective fields H_D and H_E in $FeBO_3$ were determined in Refs. 3 and 4, respectively.

Figure 1 shows the temperature dependence of the anisotropy field H_{eq} (crystal #1). Measurements were conducted in the temperature region 1.5–77 K at a frequency of 35.9 GHz, and in 77–300 K at frequencies of 12.2–8 GHz. Clearly, temperature compensation occurs at $T_c = 5$ K ($T \rightarrow T_c$ in a low-temperature region) at which point the effective magnetic anisotropy field H_{eq} changes sign. This should lead to a condition that below T_c (in the absence of external effects and excluding the demagnetizing field) an energetically advantageous state occurs when the antiferromagnetic vector

$$\mathbf{l} = \frac{\mathbf{M}_1 - \mathbf{M}_2}{2M_0}$$

($\mathbf{M}_1$ and $\mathbf{M}_2$ are sublattice magnetic moments) is parallel to one of the second-order axes C_2. In the temperature region $T_c < T < 300$ K, **l** is perpendicular to C_2 and lies at a small angle with the crystal basal plane.[5] We should note that when recording AFMR in the vicinity of T_c a temperature hysteresis of the resonant field is observed. In addition to this, weak splitting of the AFMR lines is observed in the region below 3 K with the **H** field configured along C_2, which does not exceed 15 Oe at 1.5 K.

Measurements carried out on different $FeBO_3$ crystal at liquid helium temperatures are scattered considerably with respect to values of the field hexagonal anisotropy (see Table I).

Concurrently, values of H_{eq} vary only slightly from crystal to crystal at $T = 77$ K and are close to data in Ref. 5.

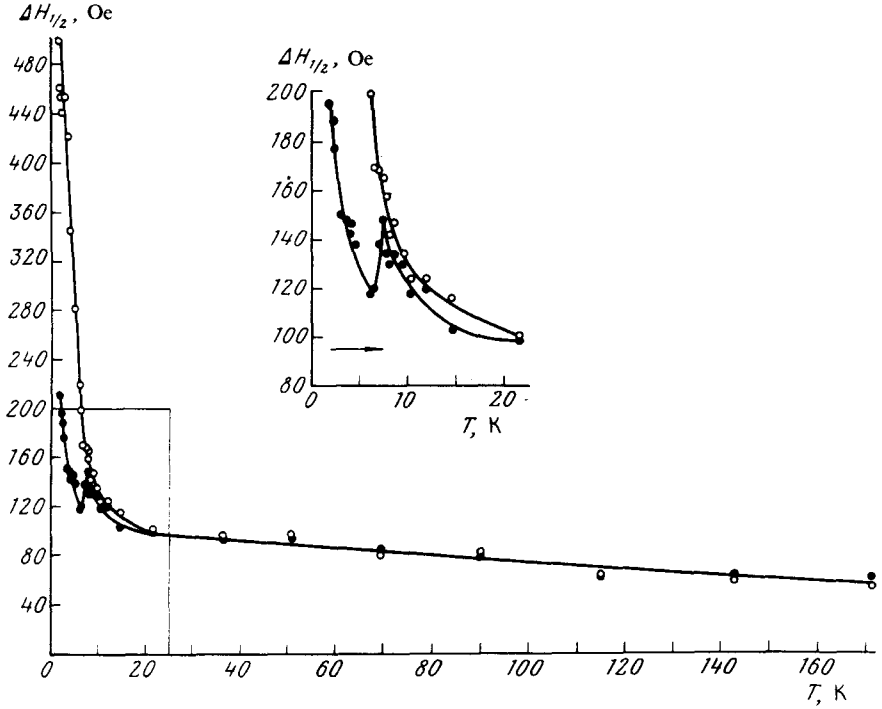

FIG. 2. Dependence of AFMR Line width ($\Delta H_{1/2}$) of $FeBO_3$ single crystal (crystal #4) measured at 35.9 GHz at given orientation of external magnetic field in the basal plane of crystal (●—$H \| C_2$, ○—$H \perp C_2$). Region near the compensation point shown in the inset, where arrow indicates direction of temperature change.

The nature of function $H_{eq}(T)$, measured for crystal #4 which most significantly varies from #1 in terms of parameters of field hexagonal anisotropy at $T = 4.2$ K, is similar to Fig. 1. However, H_{eq} values of these crystals in the region 1.5–10 K vary significantly although at higher temperatures the hexagonal anisotropy fields differ only slightly. Temperature compensation in specimen #4 ($T \to T_c$ in low-temperature region) is shifted by 2.5 K with respect to T_c in specimen #1, and is 7.5 K.

When **H** is rotated in the basal plane the AFMR line width ($\Delta H_{1/2}$) at low temperatures varies as $\cos 6\phi$ which, clearly, is associated with the periodic emergence of the antiferromagnetic vector **l** from the plane (111) as the angle ϕ changes. Emergence from plane (111) depends on the presence of the fourth-order term $q[l_x^3 - 3l_y^2 l_x]l_z$ in the thermodynamic potential[6] which is partly responsible for the energy of basal anisotropy of a crystal. At $T \to T_c$ below 6–8 K, $\Delta H_{1/2}(H \| C_2)$ increases rapidly (Fig. 2) and at the compensation point converges to a value of $\Delta H_{1/2}(H \perp C_2)$, attesting to the fact that a spin-reorienting phase transition occurs near T_c in the external field at which vector **l**, aligned perpendicularly to one of the C_2-axes at a small angle with the plane (111), takes a position in the basal plane of a crystal and aligns paralleling with the C_2-axis.

The foregoing results lead to the assumption that iron borate crystals—synthe-

sized by means of technological processes[3,7]—contain impurities that at low temperatures affect the width of the AFMR lines and the energy of anisotropy in the basal plane. On the other hand, a change in the sign of H_{eq} and the corresponding spin reorientation in the basal plane may be the inherent property of pure $FeBO_3$ as, for example, is the Morin transition in α-Fe_2O_3. Additional investigtion will be undertaken to elucidate this problem.

[1)]Before this work, hexagonal anisotropy of iron borate crystals was observed at $T = 77$ K by means of the acoustical resonance method.[5]

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