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MAGNETISM AND FERROELECTRICITY

Deaccommodation of the Initial Permeability in $FeBO_3$ at Low Temperatures

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Abstract—Deaccommodation of the initial permeability μ in the weak ferromagnet $FeBO_3$ is studied experimentally. The temperature dependence of the relaxation time is determined, and the activation energy is found. Based on the results obtained, the conclusion is made that the deaccommodation of μ in iron borate at low temperatures is related to the same carriers that participate in various photoinduced magnetic transformations in this compound.

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1. INTRODUCTION

Iron borate is a weak ferromagnet. Its specific features (transparency in the visible optical range, the existence of an uncompensated magnetic moment, a fairly high temperature of the transition to a paramagnetic state) make it inviting for practical use. This material exhibits unusual magnetooptic and magnetoelastic effects [1] that are still not clearly understood. The mechanism of photoinduced self-oscillations of band structures that occur in $FeBO_3$ at low temperatures remains unclear [2, 3].

In this work, we studied the initial permeability in iron borate for various initial states of the magnetic system.

2. SAMPLES AND EXPERIMENTAL TECHNIQUE

The samples under study were $FeBO_3$ single crystals grown by the gas-transport reaction method in the form of 50-μm-thick plates with linear dimensions larger than 2×2 mm.

The magnetic permeability was measured by the inductive method using two coils located in an ac magnetic field h at a frequency of 140 Hz. The coils were connected so that the induction signal from them was zero in the absence of a sample. When a sample was placed into one of these coils, their balance was disturbed. By measuring the induction signal, the permeability μ was determined. When measuring the temperature dependences, the coil balance was achieved using a static magnetic field large enough for sample saturation.

The field was applied perpendicular to the probe ac field. When the temperature was varied, the balance of the system was maintained using an additional coil located outside the cryostat.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 1 shows the dependence of μ at various temperatures on the time elapsed from the moment at which the dc magnetic field applied perpendicular to the direction of the probe field was turned off. As seen from Fig. 1, the magnetic permeability decreases over the course of time (i.e., it undergoes deaccommodation) in the temperature range studied. As the temperature increases above 77 K, the effect is enhanced and the relaxation time decreases.

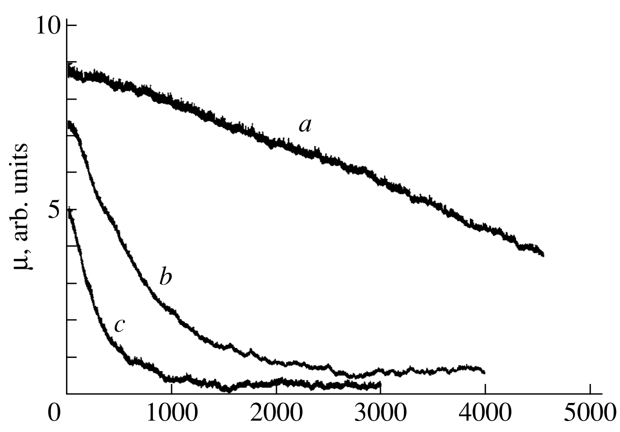

Fig. 1. Deaccommodation of the initial magnetic permeability in $FeBO_3$ at various temperatures T: 128 (a), 149 (b), and 157 (c) K. The reading started from the moment at which the dc magnetic field h = 18 mOe was removed.

Based on the data obtained, we can establish the activation energy E_a using the temperature dependence of the relaxation time τ written in the form

$$\tau = \tau_0 e^{E_0/kT}, \quad (1)$$

where τ_0 is a parameter dependent on the nature of activated carriers and k is the Boltzmann constant. From this formula, we obtain $E_a = 0.30 \pm 0.05$ eV.

As is known, the magnetic permeability in $FeBO_3$ undergoes anomalous variations with temperature [3]. There are two temperature ranges in which the $\mu(T)$ dependences are different. Figure 2 shows that, in the low-temperature range, the $\mu(T)$ variation depends on the initial state of the magnetic system. Storage in the absence of a dc magnetic field results in a change in the temperature dependence of the magnetic permeability. After storage for 60 s, the minimum value of μ is observed at $T \approx 140$ K, while without storage the magnetic permeability reaches a minimum at $T \approx 180$ K.

As the temperature decreases below 140 K, the μ deaccommodation effect decreases even under long-term storage. Below this temperature, iron borate exhibits photoinduced magnetic effects, in particular, a light-induced increase in the magnetic permeability [4], whose temperature dependence is shown in Fig. 2. The activation energy of light-excited centers is 0.28 eV [4], which coincides with the activation energy determined from the deaccommodation of μ. This result shows that the photomagnetic effects and the relaxation of the magnetic permeability in $FeBO_3$ are associated with the same centers.

As is known, the μ deaccommodation is due to the formation of additional potential barriers that inhibit variation of the initial magnetic state by an external field. The barrier formation is caused by the diffusion of defects (in this case, electrons) to the crystal lattice sites that are energetically favorable when a magnetic moment exists. As the temperature decreases, the electrons are "frozen" in their initial positions. On illumination, these electrons can be activated and transfer to nonequilibrium positions. As a result, the photoinduced effect and deaccommodation can oppositely influence the value of μ, which is the case in iron borate.

It should be noted that all of the anomalies in the behavior of the magnetic permeability in iron borate are

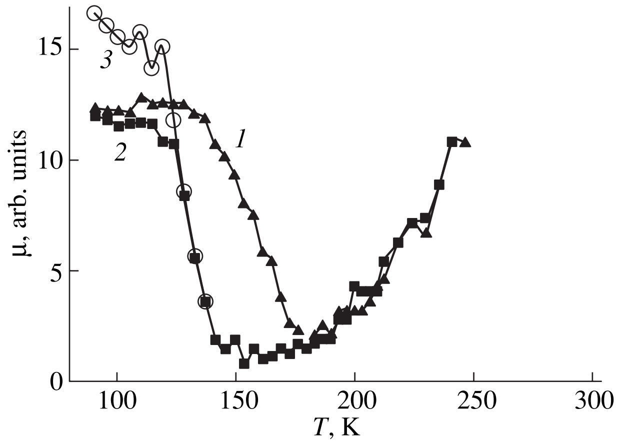

Fig. 2. Temperature dependence of the initial magnetic permeability of $FeBO_3$ measured (*1*) without storage of the initial magnetic state and (*2*) after storage for 60 s. (*3*) The variation in μ under illumination with light. $h = 18$ mOe.

observed in low magnetic fields. As established in [3], at low temperatures, the initial magnetic permeability of $FeBO_3$ is due to the presence of magnetic band structures. These structures seem to be stabilized by electron diffusion or to be excited by light. In strong fields, where there is a contribution from domain-wall motion, the anomaly in the temperature dependence of the magnetic permeability and the deaccommodation of μ are slight.

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