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Angular dependence of magnetization in axially stressed $FeBO_3$ single crystals

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Magnetization processes in easy-plane weak ferromagnetic $FeBO_3$ under magnetic field H and axial pressure P applied simultaneously in basal plane of the crystal have been investigated. The absence of expected orientational phase transition on the experimental curve $M_H(P)$ has been interpreted as degeneration of two magnetic phases into one in case of no parallelism between magnetic field and the pressure. Experimental curves $M_H(H)$ at fixed pressure for different values of angle between magnetic field and pressure directions have been constructed. Correlation between the theory and the experiment one can observe in this case as well.

Исследованы процессы намагничивания легкоплоскостного слабого ферромагнетика $FeBO_3$ при одновременном воздействии магнитного поля H и аксиального давления P, приложенных в базисной плоскости кристалла. Отсутствие ожидаемого ориентационного фазового перехода на экспериментальной кривой $M_H(P)$ интерпретировано как вырождение двух магнитных фаз в одну в случае, когда магнитное поле и давление не параллельны друг другу. Построены экспериментальные кривые $M_H(H)$ при фиксированном давлении для различных значений угла между направлениями поля и давления. В этом случае также наблюдается корреляция между теорией и экспериментом.

Iron borate, $FeBO_3$, is an easy-plane weak ferromagnetic. Due to peculiarities of its crystal and magnetic structure, magnetoelastic interaction is very pronounced in this crystal. Therefore, the mechanical boundary conditions influence considerably the experimental results. In many cases, such an influence cannot be measured directly because of non-controllable experimental boundary conditions. So, to describe experiment adequately, one has to model boundary conditions theoretically (see [1]). In this work, we attempt to model the boundary conditions experimentally.

Magnetization processes in $FeBO_3$ single crystals in the presence of pre-specified axial pressure values were investigated at room temperature. For this purpose, we have synthesized iron borate basal plates of up to 100 μm thickness. The pressures applied in basal plane were produced by normal compressing force acting directly on two opposite faces perpendicular to said plane. The magnetic field in basal plane could be oriented at arbitrary angle α to the pressure direction. In our previous work [2], the magnetic field and pressure were mutually parallel. To provide the angle α variation, we had to modify considerably the magneto-optical magnetometer (Fig. 1) used in [2].

Fig. 2a demonstrates experimental pressure dependence of magnetization $M_H(P)$ at fixed magnetic field parallel to the pressure axis. To explain the $M_H(P)$ curve behavior,

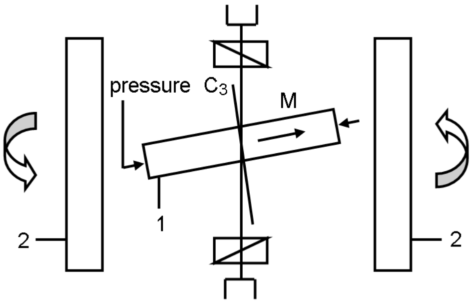

Fig. 1. Modified magneto-optical magnetometer with axial pressure device: *1* – the sample; *2* – Helmholtz coils.

we used the theory [3]. According to [3], the magnetization process in a weakly ferromagnetic crystal, such as $FeBO_3$, under mutually parallel uniaxial pressure and magnetic field includes two phases divided by spin-reorientation 2nd order transition (Fig. 2b, curve *1*). These phases are the collinear and angular ones. However, in experiment, the phase transition is not localized at a point exactly, that may be associated with inhomogeneous distribution of the real pressure in the crystal. One more reason of the distinction may consist in not exact parallelism between the magnetic field and pressure in experiment.

We have generalized the theory [3] for the case of an arbitrary angle α. In this case, the magnetization curves $M_H(H)$ and $M_H(P)$ are defined by the expressions

$$PB_{66}H_E\,(M_\perp \cos + M_H \sin\alpha) \times$$
$$\times\,(M_H \cos\alpha - M_\perp \sin\alpha) =$$
$$= 4M_0C_{66}HM_\perp(HM_H + H_DM),$$
$$M_\perp = \sqrt{M^2 - M_H^2}.$$

Here, H_E is the exchange field; H_D, the Dzyaloshinsky field; M_0, the sublattice magnetization; M, the spontaneous magnetization; C_{66}, B_{66} are elastic and magnetoelastic constants, respectively. The calculated $M_H(P)$ curves at fixed H for different angles α are presented in Fig. 2b. Our theory shows that two said magnetic phases have to degenerate into a single one if the uniaxial pressure and magnetic field are non-parallel. Theoretical curves (Fig. 2b) are in good correlation with experiment (Fig. 2a).

Fig. 3 presents the experimental (Fig. 3a) and theoretical (Fig. 3b) $M_H(H)$ curves at fixed pressure for different angles α. A qualitative agreement between the theory and the experiment is observed in this case as well. The possible reasons for quantitative differences are inhomogeneous stress distribution in the sample and inaccuracy of angle α determination.

We took advantage of magneto-optical magnetometer use to visualize the sample magnetic state under axial pressure. Fig. 4 shows the influence of axial pressure on domain structure of the crystal. The pressure axis is oriented nominally in vertical (in the plane of the picture) direction. The magnetic field is absent. The strip domain structure testifies that said inhomogeneity in the stress distribution is nevertheless not very significant.

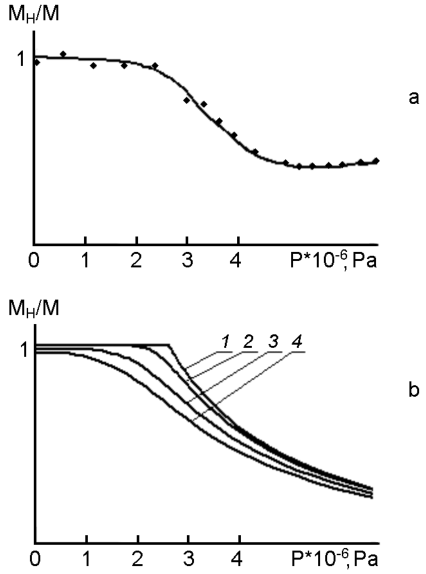

Fig. 2. $M_H(P)$ curves: experiment (a); theory (b). α (deg): 0 (*1*), 2 (*2*), 7 (*3*), 12 (*4*).

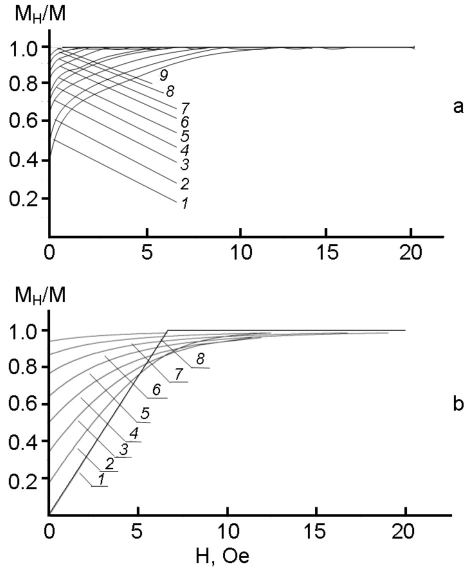

Fig. 3. $M_H(H)$ curves. α (deg): 0 (*1*), 10 (*2*), 20 (*3*), 30 (*4*), 40 (*5*), 50 (*6*), 60 (*7*), 70 (*8*), 80 (*9*). (a), experiment; (b), theory.

References

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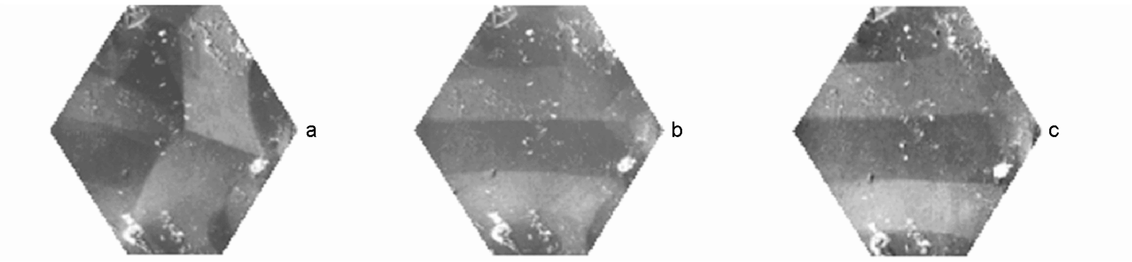

Fig. 4. Influence of axial pressure on domain structure (pressure axis is vertical, $H = 0$): $P = 0$ (a) $0.35 \cdot 10^7$ Pa (b), $0.7 \cdot 10^7$ Pa (c).

Кутова залежність намагніченості в аксіально напруженому монокристалі $FeBO_3$

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Досліджено процеси намагнічування легкоплощинного слабкого феромагнетику $FeBO_3$ при одночасній дії магнітного поля H та аксіального тиску P, прикладених у базисній площині кристала. Відсутність очікуваного орієнтаційного фазового переходу на експериментальній кривій $M_H(P)$ інтерпретовано як виродження двох магнітних фаз в одну у випадку, коли магнітне поле та тиск не є паралельними одне одному. Побудовано експериментальні криві $M_H(H)$ при фіксованому тиску для різних значень кута між напрямками поля та тиску. У цьому випадку також спостерігається кореляція між теорією та експериментом.