DEPENDENCE OF MAGNETOCRYSTALLINE ANISOTROPY ON FIELD INTENSITY IN HEXAGONAL BARIUM FERRITE

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In monocrystals of $BaSc_{1.8}Fe_{10.2}O_{19}$ there was observed a strong dependence of the magnetic anisotropy constant on the magnetic field intensity H. In fields $H < H_K$ the crystals possess an axis, in fields $H > H_K$ a plane, of easy magnetization. The results are explained by use of a model of two magnetic sublattices with weak exchange interaction between them.

In description of the magnetic properties of ferrites in the region of technical magnetization, no account is taken of their sublattice structure, since the exchange interaction between the sublattices is quite large in comparison with the exchange interaction within the sublattices. The magnetization processes in such ferrites are determined by the behavior of the resultant magnetization vector and are similar to the behavior of ordinary ferromagnets.

For crystals with hexagonal symmetry, the energy of magnetic anisotropy in this case is described in the following form:

$$E_K = K_1 \sin^2\vartheta + K_2 \sin^4\vartheta \\ \ldots + K_3 \sin^6\vartheta \cos 6\varphi, \quad (1)$$

where K_1, K_2, and K_3 are magnetic anisotropy constants, and θ and φ are the polar coordinates of the resultant magnetization vector.

If, however, the exchange interaction between the sublattices is small in comparison with the exchange interaction within the sublattices[1], then description of the anisotropy energy in the form (1) is inappropriate. If we restrict ourselves to the case of two magnetic sublattices, then the energy of magnetic anisotropy for a crystal of hexagonal symmetry, in the first approximation of perturbation theory, must be written in the form

$$E_K = k \sin^2\psi + k' \sin^2\psi' + k'' \cos\psi \cos\psi' + k''' \sin\psi \sin\psi', \quad (2)$$

where ψ and ψ' are the angles between the sublattice magnetizations $\mathbf{M}_1$ and $\mathbf{M}_2$ and the principal axis of symmetry of the crystal (Fig. 1). The anisotropy constants in the expression (2) are functions only of the temperature and are independent of the value of the magnetic field. But if, in the analysis of the experimental results, one uses the expression for the anisotropy energy in the form (1) as being simpler, then the coefficients in the expression (1) will not be constant quantities, but will depend on the magnetic field intensity H. With the aid of the relation

$$\operatorname{tg}\vartheta = (M_1 \sin\psi + M_2 \sin\psi') / (M_1 \cos\psi + M_2 \cos\psi')$$

one can compare the expression (2) with the first term of the series (1). Then K_1 will depend not only on k, k′, k″, k‴, M_1, and M_2, but also on ψ and ψ'. If in the magnetization process the mutual orientation of the sublattice magnetizations changes, then K_1 depends, through ψ and ψ', on the value of the field.

In the present research, an investigation was made of the magnetic anisotropy of monocrystals of the hexagonal ferrite $BaSc_{1.8}Fe_{10.2}O_{19}$. The magnetic properties of monocrystals of the system $BaSc_xFe_{12-x}O_{19}$ were described in[2], where it was shown that for monocrystals with x = 1.8 there exists a certain range of temperature in which the crystals possess a plane of easy magnetization. Outside of it, the direction of easy magnetization coincides with the hexagonal axis. A discussion of the results was given in[2] with the aid of formula (1); only the first term was taken into account.

Among the specimens of the composition

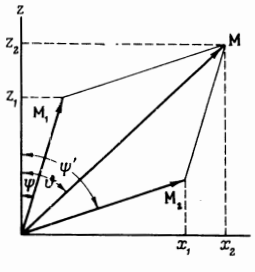

FIG. 1. Configuration scheme of the sublattice magnetizations $\mathbf{M}_1$ and $\mathbf{M}_2$ and of the total magnetization $\mathbf{M}$. $x_1 = M_2 \sin\psi'$, $x_2 - x_1 = M_1 \sin\psi$, $z_1 = M_1 \cos\psi$, $z_2 - z_1 = M_2 \cos\psi'$.

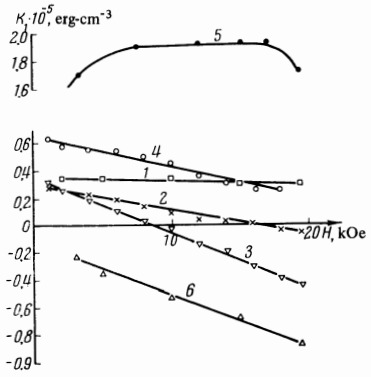

FIG. 2

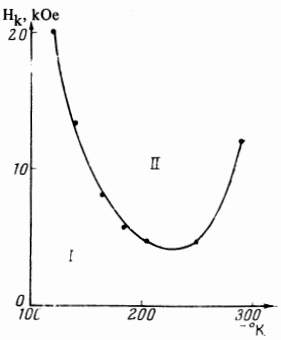

FIG. 3

FIG. 2. Dependence of the magnetic anisotropy constant K_1 of a monocrystal of $BaSc_{1.8}Fe_{10.2}O_{19}$ on magnetic field intensity at various temperatures. For specimen No. 1: Curve 1, T = 305°K; Curve 2, 293°K; Curve 3, 217°K; Curve 4, 140°K; Curve 5, 77°K. For specimen No. 2: Curve 6, T = 293°K.

FIG. 3. Temperature dependence of the field of transition from an axis to a plane of easy magnetization, H_K, for a monocrystal of $BaSc_{1.8}Fe_{10.2}O_{19}$.

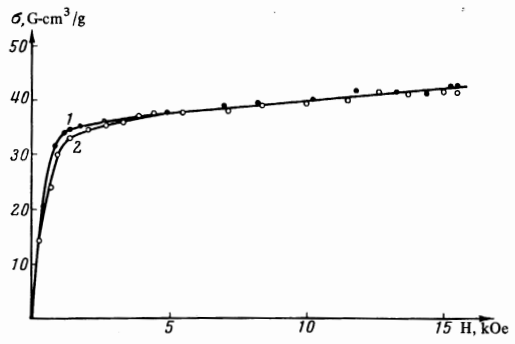

FIG. 4. Magnetization curves of a moncrystal of $BaSc_{1.8}Fe_{10.2}O_{19}$ at 293°K: Curve 1, H||c; curve 2, H⊥c.

$BaSc_{1.8}Fe_{10.2}O_{19}$ there were specimens that differed from one another with respect to the value of tne magnetization and the value (and also the sign) of the anisotropy. This is not disturbing, since the dependence of magnetic properties on composition is very abrupt[2] and the chemical analysis was made from a mass of 10 to 20 crystals, i.e., is an average. The magnetic anisotropy constant changes sign right in the neighborhood of the composition $BaSc_{1.8}Fe_{10.2}O_{19}$. For investigation, the two specimens were chosen that differed most greatly from each other. Curves for these two monocrystals were taken by the torque method in magnetic fields of different intensities. Figure 2 shows the dependence of K_1 on the magnetic field intensity. Hereafter we shall discuss all results for specimen No. 1.

In weak fields, K_1 is positive. Consequently, in these fields the crystal has an axis of easy magnetization. In strong fields, K_1 is negative; that is, the crystal possesses at these fields a plane of easy magnetization. At each temperature there is a certain magnetic field H_K at which the anisotropy constant K_1 goes through zero. The dependence of H_K on temperature is shown in Fig. 3. In region I the crystal possesses an axis, in region II a plane, of easy magnetization.

The dependence of K_1 on the magnetic field intensity was observed in the temperature range from 77°K (no investigation was made at lower temperatures) to 300°K. Above 300°K, K_1 ceases to depend on H, i.e., actually becomes constant. Above 120°K, a linear dependence of K_1 on H is observed; below this temperature, it is nonlinear.

Neutron-diffraction investigation of scandium-substituted hexagonal ferrites with structure of type M ($BaSc_xFe_{12-x}O_{19}$) has shown[3] that the nonmagnetic scandium ions are located in the structure at positions with fivefold coordination, which leads to a weakening of the exchange bonds between the magnetic sublattices. Within each sublattice the usual collinear ordering of spins is retained, but the resultant magnetic moments of the sublattices are noncollinear.

In the range of temperature in which dependence of K_1 on H is observed, there apparently occurs a change of the mutual orientation of the sublattice magnetizations M_1 and M_2 because of weak exchange interaction between them. The absence of saturation in magnetization curves (Fig. 4) taken along the hexagonal axis (Curve 1) and along the basal plane (Curve 2) supports this point of view. Above 300°K, furthermore, K_1 ceases to depend on the magnetic field. This is in full agreement with neutronographic investigation of this crystal[3], in which it is shown that above 300°K the structure becomes collinear.

[1] D. G. Sannikov and T. M. Perekalina, Zh. Eksp. Teor. Fiz. 56, 730 (1969) [Sov. Phys.-JETP 29, 396 (1969)].

[2] T. M. Perekalina and V. P. Cheparin, Fiz. Tverd. Tela 9, 3205 (1967) [Sov. Phys.-Solid State 9, 2524 (1968)].

[3] O. P. Aleshko-Ozhevskiĭ, R. A. Sizov, I. I. Yamzin, and V. A. Lyubimtsev, Zh. Eksp. Teor. Fiz. 55, 820 (1968) [Sov. Phys.-JETP 28, 425 (1969)].

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188