The nature of the small contribution to the magnetostriction of Fe^{2+} ions in spinel ferrites

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The behavior of the magnetostriction λ of chromite ferrite Fe_2CrO_4 is studied and compared with the behavior of the magnetostriction of magnetite Fe_3O_4. Chromite ferrite is found to have an anomalously high magnetostriction. It is suggested that electron hopping $Fe^{2+} \rightleftarrows Fe^{3+}$ has a substantial effect on the contribution of the Fe^{2+} ions to the magnetostriction.

It is generally believed[1] that the Co^{2+} and Fe^{2+} ions, which have partially unquenched orbital angular momenta (triplet states) in the octahedral positions (B sites), are responsible for the large contributions to the magnetic anisotropy and magnetostriction of ferrites. We know, however, that spinel ferrites with Co^{2+} ions do in fact exhibit an appreciable magnetostriction, whereas in ferrites with Fe^{2+} ions it is low.[2] It is of interest, therefore, to determine what causes the magnetostriction of Fe^{2+} ions to be low.

The spinel ferrites containing Fe^{2+} ions generally also contain Fe^{3+} ions in the B sites, giving rise to electron hopping: $Fe^{2+} \rightleftarrows Fe^{3+}$. In ferrites of this sort, the iron ions in B sites therefore have a mixed valence. We suggest that this circumstance is the principle cause of the low magnetostriction and low anisotropy.

To verify this assumption, we used as test objects a magnetite with an equal number of Fe^{2+} and Fe^{3+} ions in the B sites: $Fe^{3+}[Fe^{2+}Fe^{3+}]O_4$ and chromite ferrite Fe_2CrO_4 with no Fe^{3+} ions in the B sites: $Fe^{3+}[Fe^{2+}Cr^{3+}]O_4$. We chose to study their magnetic and electric properties and to compare the results of these studies. Since the Fe_2CrO_4 sample[3] has only a cubic lattice, we compared it with the data on magnetite when the magnetite sample was in the cubic phase, i.e., when its temperature was higher than that of the Vervey transition.

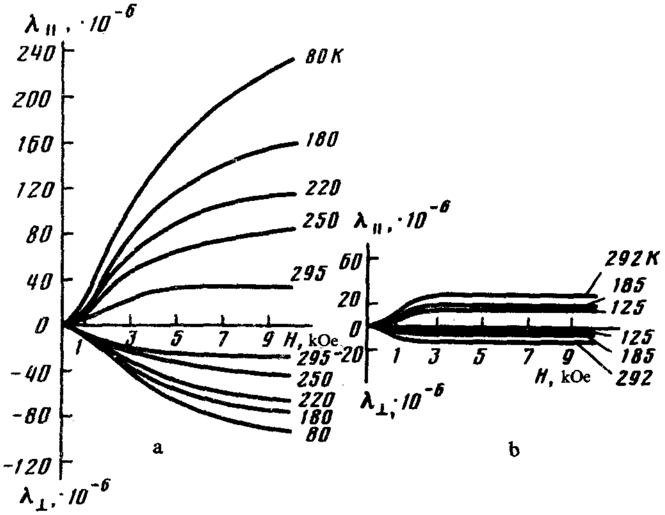

FIG. 1. a—Magnetostriction isotherms of a polycrystalline Fe_2CrO_4 sample; b—magnetostriction isotherms of a polycrystalline magnetite sample.

The Fe_3O_4 and Fe_2CrO_4 samples were synthesized with the use of ceramic technology. The first annealing of the samples was carried out at 1100 °C for 2 hours in a $CO_2 + H_2$ medium. The final baking was done at 1300 °C for 4 hours in the same medium. An x-ray structural analysis showed that these samples are single-phase spinels. The magnetostriction was measured with use of strain gauges in fields up to 10 kOe over a temperature interval 80–295 K.

To show that the hopping mechanism is not important in the conductivity of the Fe_2CrO_4 sample, we have measured its resistivity. We found that at 120 K its resistivity is $\rho \cong 3.39 \times 10^4\ \Omega \cdot \mathrm{cm}$, whereas the resistivity of magnetite is $\rho \cong 1.45 \times 10^4\ \Omega \cdot \mathrm{cm}$.

Figures 1a and 1b show the magnetostriction isotherms for both samples. We see that the magnetostriction of the Fe_2CrO_4 sample is nearly an order of magnitude greater than that of magnetite. We should bear in mind that the longitudinal and transverse magnetostrictions, $\lambda_{\parallel}$ and $\lambda_{\perp}$, of magnetite become saturated even in small fields, whereas $\lambda_{\parallel}$ and $\lambda_{\perp}$ of the Fe_2CrO_4 sample are anisotropic even in large fields, i.e., they do not become saturated. This behavior is evidence that the magnetic anisotropy of the Fe_2CrO_4 test sample is high. The measurements of the hysteresis loops show that at $T = 120$ K the coercive force of Fe_2CrO_4 is $H_c = 279$ Oe, whereas the coercive force of magnetite is $H_c = 10$ Oe. A large magnetostriction and a pronounced magnetic anisotropy can occur only in those spinel ferrites with a cubic crystal lattice which have magnetic ions with a partially quenched orbital angular momentum.

Figure 2 shows the temperature dependence of the longitudinal magnetostriction $\lambda_{\parallel}(T)$(in a 10-kOe field) for Fe_3O_4 and Fe_2CrO_4 samples. We see that if the magnetostriction of magnetite remains virtually constant upon lowering the temperature, the longitudinal magnetostriction $\lambda_{\parallel}$ of the Fe_2CrO_4 sample will increase markedly.

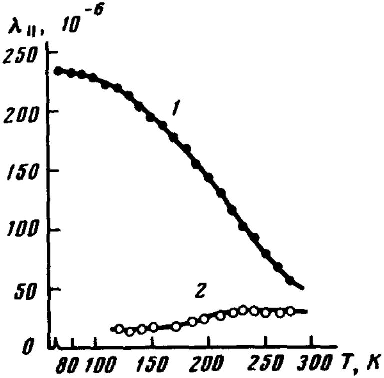

FIG. 2. Temperature dependence of the longitudinal magnetostriction $\lambda_{\parallel}$ ($H = 10$ kOe) for the Fe_2CrO_4 sample (1) and for the Fe_3O_4 sample (2).

These results thus confirm our assumption concerning the effect of the hopping mechanism $Fe^{2+} \rightleftarrows Fe^{3+}$ on the contribution of octahedral Fe^{2+} ions to the magnetostriction of spinel ferrites.

[1] S. Krupichka, Fizika ferritov i rodstvennykh im soedinenii (The Physics of Ferrites and Related Compounds), Mir, Moscow, Vol. 2, 1976, p. 29.
[2] S. Krupichka, ibid, Vol. 2, 1976, p. 77.
[3] G. L. Robbins *et al.*, J. Phys. Chem. Solids **32**, 717 (1971).

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