MAGNETOSTRICTION OF YTTRIUM TERBIUM IRON GARNETS AT LOW TEMPERATURES

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The magnetic and magnetostrictive properties of polycrystalline iron-garnets $Tb_xY_{3-x}Fe_5O_{12}$ (x varies from 0 to 3) were investigated in the temperature range 4.2—100°K. A sharp increase was observed in the magnetostriction with increase in the concentration of Tb^{3+} ions, and an absence of a clear correlation between the temperature dependences of the magnetostriction and the magnetization for samples with high terbium content (x > 1). The results do not agree with the single-ion model of magnetoelastic interaction of Néel ferromagnets.

EARLIER[1,2], a gigantic increase in the magnetostriction, the nature of which is still unclear, was observed in terbium iron garnet at low temperatures.

In the present research, the longitudinal magnetostriction of mixed iron garnets $Tb_xY_{3-x}Fe_5O_{12}$ (x varies from 0 to 3) was measured by a capacitance method in the temperature range 4.2 to 100°K. The measurements were made with a superconducting solenoid, which makes it possible to obtain magnetic fields up to 30 kgauss. The polycrystalline specimens of the ferrite were prepared by means of the usual ceramic technology; the purities of the initial oxides were: Y_2O_3—99.996% and Tb_2O_3—99.980%. At the same time as the measurements of the magnetostriction, curves of the temperature dependence of the magnetization $\sigma(T)$ were made in the superconducting solenoid. These curves show that the replacement of the nonmagnetic ions Y^{3+} by the magnetic ions Tb^{3+} leads to the appearance of $\sigma(T)$ curves with an anomalous decrease in the magnetization near 0°K and of curves with a compensation point.

Figure 1 shows the temperature dependence of the magnetostriction and the magnetization of the iron-garnets with different amounts of terbium. From these curves, one can notice the following features.

1. At low temperatures the magnetostriction increases sharply with increase in concentration of the terbium ions. Thus, if for iron garnet $Tb_{0.8}Y_{2.2}Fe_5O_{12}$ we have $\lambda = 62 \times 10^{-6}$, then for the sample $Tb_3Fe_5O_{12}$ we will have $\lambda = 2180 \times 10^{-6}$. Our measurements of Young's modulus of yttrium-terbium iron garnets at low temperatures make it possible to estimate the value of the magnetoelastic energy of the samples investigated. For terbium iron garnet at 4.2°K, it amounts to 4.75×10^6 erg/cm^3, at 80°K—0.11×10^6 erg/cm^3. We note that according to the data of Pearson[3] the energy of the anisotropy of this iron-garnet at 80°K amounts to 0.76×10^6 erg/cm^3.

2. The samples which have magnetic compensation points (T_c) in the studied temperature range reveal minima in the vicinity of T_c on the $\lambda(T)$ curves, which are the sharper the lower the compensation temperature of the sample and consequently the larger its magnetization at this temperature. For ferrites, whose magnetic compensation point lies above ~50°K, the magnetostriction compensation points are expressed less sharply than, for example, in the sample $Tb_{1.2}Y_{1.8}Fe_5O_{12}$, for which $T_c \approx 60$°K (Fig. 1b).

3. For samples with a large amount of terbium (x > 1) at low temperatures correlations are absent between the magnetization and the magnetostriction. Thus, for the iron garnet $Tb_3Fe_5O_{12}$ the magnetostriction in the temperature range 4.2×30°K increases by 2.5 times, while the magnetization in the same temperature range increases only by 6% (for the $Tb_2Y_1Fe_5O_{12}$ in the same range of temperatures the magnetostriction increases 2.7 times, the magnetization by 7%). These results do not agree with the phenomenological theory of magnetoelastic interaction developed for Néel ferromagnets in the work of Callen and others.[4] According to this theory, the temperature dependence of the coefficient of magnetoelastic coupling at low temperatures is determined by the temperature dependence of the magnetization of the sublattices:

$$B(T) = \sum_n B_l(n) m_n^{l(l+1)/2},$$

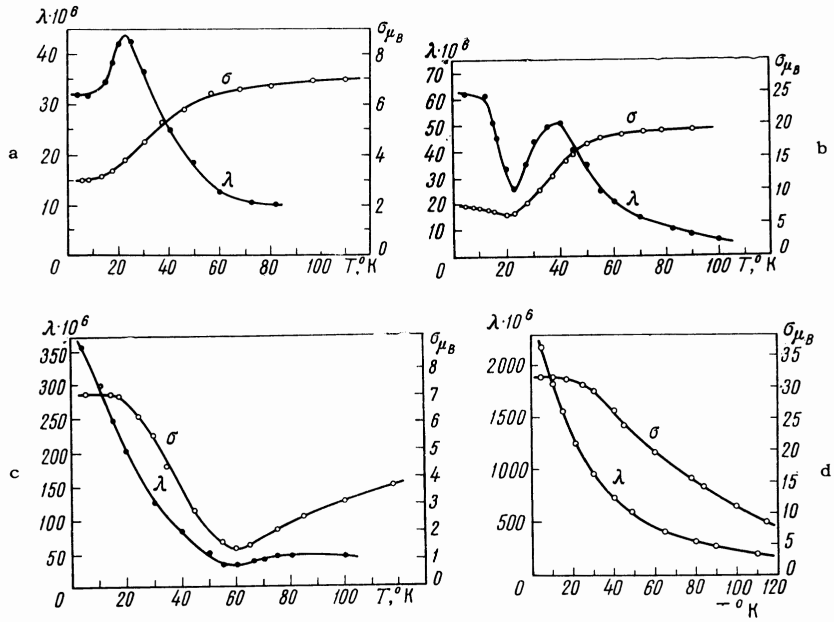

FIG. 1. Temperature dependence of the magnetostriction and the magnetization of saturation for iron garnets of the system $Tb_xY_{3-x}Fe_5O_{12}$; H = 25 kgauss, a – x = 0.5; b – x = 0.8; c – x = 1.2; d – x = 3.

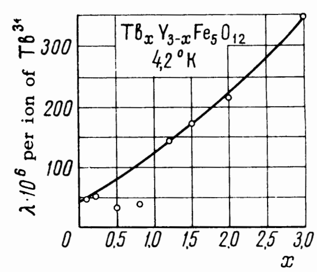

FIG. 2. Dependence of the magnetostriction, calculated for a single ion of Tb^{3+} on the component x of iron garnets of the system $Tb_xY_{3-x}Fe_5O_{12}$. T = 4.2°K, H = 25 kgauss.

where $B_l(n)$ are the temperature-independent coefficients of magnetoelastic coupling of each of the magnetic sublattices n; m_n is the magnetization of the sublattice, l is the power of the spin operators of the individual ions, which can take on values 2, 4, 6, ... However, an estimate carried out for yttrium iron garnet (YIG)[4] showed that terms with $l > 2$ give a contribution ~5–10%. Thus at low temperatures, where the magnetostriction of the ferrite garnet is determined by the rare earth sublattice, the temperature dependence of the magnetostriction, in accord with the theory, should be close to m^3. However, our measurements of the temperature dependence of the magnetostriction make it possible to assume that either for yttrium terbium iron garnets (in any case for samples with a large content of Tb^{3+}: $x > 1$) an important contribution is made by terms of very high order ($l > 2$) or at low temperatures the sublattice coefficients of the magnetoelastic interaction $B_l(n)$ should depend on the temperature.

It should also be noted that a single ion model of the magnetoelastic interaction is set forth on the basis of the theory that has been explained (terms which enter into the magnetoelastic Hamiltonian do not depend on the correlation of the spins of the various ions), which evidently is inapplicable in the case of iron garnets with a large content of terbium. This is confirmed by Fig. 2, in which is plotted the magnetostriction of yttrium-terbium iron garnets for T = 4.2°K, computed for a single ion of terbium. As is seen from the drawing, the magnetostriction increases with increase of Tb^{3+} (samples with x = 0.5 and 0.8 for which the compensation points are close to 4.2°K are excluded), and does not remain constant as is required by the single ion under consideration.

In conclusion, the authors consider it their pleasant duty to thank Professor K. P. Belov under whose direction the work was completed and R. Z. Levitin for participation and discussion of the results.

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