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MAGNETIC PROPERTIES OF ErIG[1])

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The magnetic properties of ErIG are calculated within the framework of a one-ion model for the Er^{3+} ion subject to the crystal field, the isotropic exchange field and the applied magnetic field. The crystal field parameters are taken from ErGG, only those of second order are allowed to vary.

МАГНИТНЫЕ СВОЙСТВА ErIG

В работе для расчета магнитных свойств образца ErIG использована одноионная модель для иона Er^{3+} во внутрикристаллическом, изотропном обменном и внешнем магнитном полях. Для расчета были использованы параметры внутрикристаллического поля ErGG за исключением параметров второго порядка, которые варьировались.

I. INTRODUCTION

It is generally accepted that the easy axis of the magnetization of all rare-earth iron garnets is [111] at room temperature whereas at lower temperatures these may exhibit a more complicated magnetic phase behaviour. As regards the erbium iron garnet (ErIG), there is some confusion at low temperatures as the experiments support both the [100] and [111] axes as the easy directions (see [1] for discussion). Besides magnetic anisotropy measurements [2, 3, 4] also magnetization curves in magnetic fields up to 15 T have been published recently in a wide temperature range [5].

It is the aim of this paper to interpret the magnetic properties of the ErIG within the framework of the one-ion model as well as to discuss the simplifications used.

II. THEORY AND RESULTS

A microscopic theory of the magnetic behaviour of Er^{3+} ions in ErIG can be developed in the conventional way [6]. From the energy levels and from the wave

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functions of the Er^{3+} ion subject to the crystal field at the dodecahedral c-site, to the effective exchange field $\boldsymbol{H}_{exch}$ produced by Fe^{3+} ions, and to the applied magnetic field $\boldsymbol{H}_{appl}$, the free energy F and the magnetic moments $\boldsymbol{m}$ of the Er^{3+} ions can be calculated.

To choose the unknown crystal field (CF) parameters B_{kq} (for the definition see, e. g., [7]) in ErIG we started from the values which fit both the optical spectra of the lowest $^4I_{15/2}$ multiplet of Er^{3+} in the erbium gallium garnet (ErGG) [8] and the experimental values of the g-factor ($g_x = 4.3$, $g_y = 4.3$, $g_z = 11.3$) [8]: $B_{20} = 15$, $B_{22} = 80$, $B_{40} = -1894$, $B_{42} = 297$, $B_{44} = 882$, $B_{60} = 518$, $B_{62} = -94$, $B_{64} = 922$, $B_{66} = -46$ cm^{-1}. Except B_{20} and B_{22} all the B_{kq} in ErIG are supposed to differ only

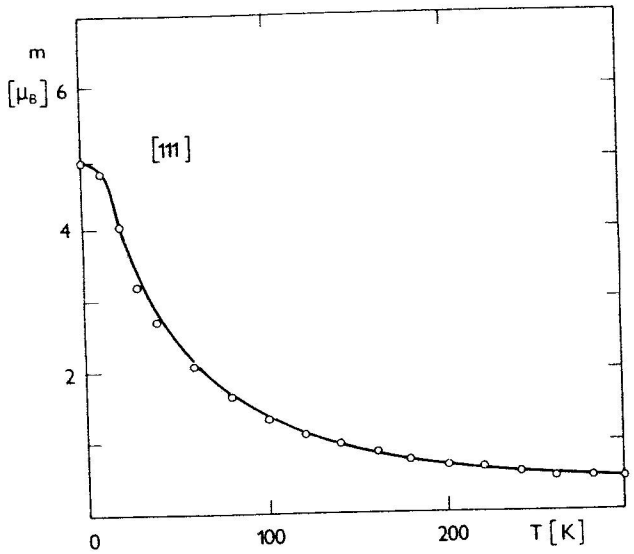

Fig. 1. Calculated temperature dependence of the magnetic moment of Er^{3+} ion in ErIG compared with the experimental values from Guillot et al. [5].

slightly from these values. As the second order parameters B_{20} and B_{22} are known to be extremely sensitive to small changes in the crystal structure [9, 10], they both were allowed to change in reasonable limits to reproduce the low temperature direction of the magnetic easy axis (i. e. [100] up to $\sim 74 \div 95$ K [11]) and the experimental value of $\Delta = F_{[111]} - F_{[100]} = 0.58$ cm^{-1} per Er^{3+} ion [12]. For the exchange field, the value 8 T was taken in agreement with [5, 13]. The same temperature dependence for $\boldsymbol{H}_{exch}$ was taken as that for the d-site iron sublattice magnetization [14] because the Re-Fe superexchange path in garnets involves predominantly the two nearest d-site Fe^{3+} ions [15].

Almost equally satisfying results were obtained for the CF parameters B_{20}, B_{22} varying within the region near the abscissa connecting points (135, 360) and (−80, 200) in the (B_{20}, B_{22}) plane. Considering, e. g., $B_{20} = 135$ and $B_{22} = 360$ cm^{-1} we get the first order transition [100] ⇄ [111] temperature ~90 K and $\Delta = 0.58$ cm^{-1}. The temperature dependence of the Er^{3+} magnetic moment in ErIG is shown in Fig. 1, its applied field dependence is displayed in Fig. 2 together with the experimental results of Guillot et al. [5]. For compensation point we get $T_c = 82$ K (cf. experimental value $T_c = 80$ K). The agreement between theoretical and experimental results is apparently satisfactory, in spite of our assumption that the exchange field is isotropic.

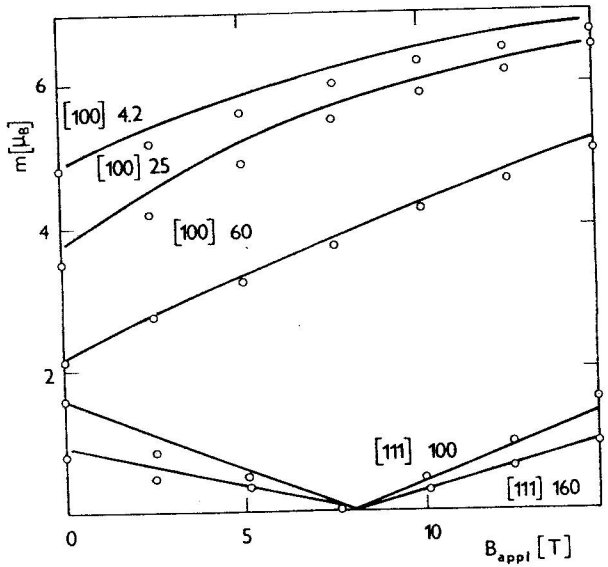

Fig. 2. Calculated applied field dependence of the magnetic moment of Er^{3+} ion in ErIG for directions [100] and [111] and five different temperatures (in Kelvins). Experimental points are from [5].

The comparison of experimental and theoretical results for the anisotropy constants K_1 and K_2 shows a larger discrepancy: the theory gives K_i (ErIG) — K_i (YIG) ~ 1800 and 40 J/m^3 at 77 K to be compared with experimental values 6000 and 200 J/m^3 [2, 3] for $i = 1$, 2, respectively. At $T = 4.2$ K the description of magnetocrystalline anisotropy using only two constants K_1 and K_2 is inadequate and a comparison with available experimental data [16] should involve more anisotropy constants.

It is worth mentioning that a noncollinear ordering of magnetic moments of the Er^{3+} ions in nonequivalent c-sites arises for both the [100] and the [111] directions

as a consequence of the anisotropy of the crystal field. At $T = 4.2$ K the calculation using the above mentioned set of B_{kq} yields two angles, 0° and 30°, for a double conical arrangement for the [100] direction and 3° and 28° for the [111] direction of the total magnetization. The neutron diffraction experiments [17] were resolved with the values of 14° and 42° for the two angles in question but under the assumption of easy [111] direction which contradicts the other experiments [5, 18, 19, 20].

III. CONCLUSIONS

The one-ion model for Er^{3+} ion with the assumption of isotropic exchange interaction works surprisingly well in the case of ErIG. The so far available values of anisotropic exchange parameters for ErIG [18] indicate that whereas those of the fourth and the sixth order are one order of magnitude less than the corresponding CF parameters, the second order parameters are comparable. As the true operators in $\mathcal{H}_{cf}$ and $\mathcal{H}_{exch}$ are not of quite the same form [21], we can only guess that the simplifying assumption of isotropic exchange is paid for in appreciable changes in the CF parameters B_{20} and B_{22}, at least partially. The incorporation of anisotropic exchange terms should be the next step and we proceed in this direction. The full account of the presented work will be published elsewhere.

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