Journal of Magnetism and Magnetic Materials 140–144 (1995) 1123–1124

ELSEVIER

journal of magnetism and magnetic materials

High-field magnetization in $Ho_{1-x}Er_xGa_2$ single crystals

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Abstract

The hexagonal antiferromagnetic compounds $HoGa_2$ and $ErGa_2$ exhibit large anisotropy with two metamagnetic-like transitions in external magnetic fields applied along the easy direction: at 1.7 and 2.4 T along the *a*-axis for $HoGa_2$, and at 0.7 and 2.0 T along the *c*-axis for $ErGa_2$. Magnetization measurements in high fields up to 40 T have been performed on single crystals of the substituted compounds $Ho_{1-x}Er_xGa_2$ ($x = 0$, 0.2, 0.4 and 0.6). In $HoGa_2$, above the metamagnetic-transition fields, the *a*-axis magnetic moment increases slowly and reaches the value of $9.75\mu_B$ at 40 T, whereas along the *c*-axis it sharply rises but to a much lower value, of $7\mu_B$ only. In substituted compounds, besides the *c*-axis transition around 6 T, an additional transition appears at 18–19 T along the *a*-axis. The transition-field values were found to decrease slightly with increasing Er content for both transitions.

The RGa_2 compounds crystallize in the simple $A1B_2$-type hexagonal structure. They are antiferromagnets with low Neél temperatures (T_N) and exhibit large magneto-crystalline anisotropy. In particular, T_N is equal to 7.6 and 7.5 K for $HoGa_2$ and $ErGa_2$, respectively [1,2]. The magnetic moments of the R^{3+} ions lie along the *a*-axis in $HoGa_2$ and along the *c*-axis in $ErGa_2$. This change of the anisotropy is understood as being related with the opposite sign of the second-order Stevens factor within the localized f-magnetism. Both compounds exhibit two metamagnetic-like transitions in external magnetic fields applied along the easy direction. The transitions occur at 1.7 and 2.4 T along the *a*-axis for $HoGa_2$ [1], whereas in $ErGa_2$, the collinear antiferromagnetic structure of $+-+-$ type along the *c*-axis changes to $+++-$ ferrimagnetic structure at 0.7 T, then to $++++$ ferromagnetic arrangement at 2.0 T [2–4].

In this paper, the results of high-field magnetization measurements, performed on single crystals $Ho_{1-x}Er_xGa_2$ with $x = 0$, 0.2, 0.4 and 0.6, are presented and discussed.

The $Ho_{1-x}Er_xGa_2$ polycrystal samples were prepared from starting metals with purity 99.9% (Ho and Er) and 99.999% (Ga) by arc-melting in helium protective atmosphere. The ingots were remelted in a resistance furnace using modified Bridgman technique for increasing the size of grains. Single crystal samples of size $(1 \times 1 \times 1)$ mm^3 were cut out of the grains and oriented by X-ray back Laue patterns. The magnetization measurements were performed in pulsed magnetic fields up to 40 T at 1.6 K in the MegaGauss Laboratory at the University of Tokyo. The measurements in semi-continuous fields for the sample with $x = 0.4$ were performed in the Amsterdam High-Field Installation up to 35 T at 1.4 K. The results of the two different measurements are practically the same. The experimental data are not available for compounds with $x = 0.8$ and 1.0 because the samples were destroyed during measurements, likely due to large magnetostrictions.

Fig. 1 show the high-field magnetization along the *a*- and *c*-axis of $HoGa_2$. The data at low fields coincide well with those reported in Ref.[1]. Along the *a*-axis, after low-field metamagnetic transitions, the magnetic moment increases slowly and reaches a value of $9.75\mu_B$/f.u. at 40 T, close to that of Ho^{3+} ions ($10\mu_B$). Along the hard direction, a deviation from a straight line was observed above 3 T, and a sharp rise to about $7\mu_B$/f.u. is found around 6–8 T, then it slowly increases to $9.3\mu_B$/f.u. at 40 T. Note that in $ErGa_2$ [2], above the metamagnetic transition, the moment along the *c*-axis reaches a value of $8.5\mu_B$, close to that of Er^{3+} ions ($9\mu_B$), whereas the magnetization along the hard direction increases linearly with increasing magnetic field up to 15 T (see also Fig. 1). The intrinsic anisotropy field H_a, roughly determined as a crossing-point of the extrapolated hard-axis line with the

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SSDI 0304-8853(94)00960-0

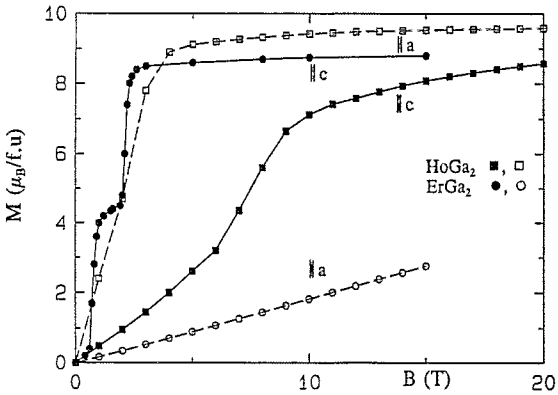

Fig. 1. The high-field magnetization at 1.6 K along the a (□) and c (■) axis of $HoGa_2$. The data for $ErGa_2$ (○, ● respectively) were measured at 1.5 K [2]. Lines are a guide for the eyes.

saturation value, exceeds 20 and 45 T for $HoGa_2$ and $ErGa_2$, respectively.

The lattice parameters are $a = 4.193$ (4.185) and $c = 4.044$ (4.018) for $HoGa_2$ ($ErGa_2$). In the substituted $Ho_{1-x}Er_xGa_2$ compounds, the lattice parameters are found to vary linearly with increasing Er concentration. Although the value of T_N is almost the same for the binary compounds, the dependence of T_N on the Er concentration in substituted compounds is complicated (see Fig. 2). T_N decreases with increasing x at $x \leq 0.45$, then increases at $x \geq 0.6$. T_N is determined as the temperature at which the magnetization curves $M(T)$ (measured in a field of 0.05 T above 1.8 K) exhibit a maximum. The maximum in $M(T)$ at T_N is observed along the a-axis only for the compounds with $x \leq 0.45$, and along the c-axis only for $x \geq 0.6$.

High-field magnetization along the a- and c-axis for the substituted compounds are shown in Fig. 3. Besides the sharp rise of the magnetic moment along the c-axis, an additional high-field anomaly appears at 18–19 T along the a-axis in all substituted compounds. The anisotropy in the basal plane is found to be negligible. The value of the transition field slightly decreases with increasing Er content for both transitions. Along the a-axis, it is evaluated to be 19.5, 18.5 and 18 T for compounds with $x = 0.2$, 0.4 and 0.6, respectively. An extrapolated value of 17 T was found for $ErGa_2$ ($x = 1.0$), implying that the additional transition is expected at 17 T for this compound. Along the c-axis, the value of the sharply rising moment around 6 T decreases with increasing Er content. The magnetic moment at 40 T along the a-axis is still larger than that along the c-axis for $x = 0.2$, whereas they become practically equal for $x = 0.4$ and 0.6. The values of magnetic moments after the metamagnetic transition roughly correspond to $x \times 8.5\mu_B$/f.u. along the c-axis and to $(1-x) \times 9.4\mu_B$ in the basal plane.

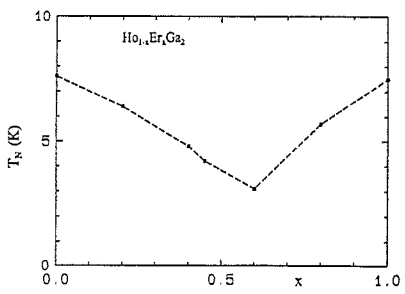

Fig. 2. The dependence of the Néel temperature on Er concentration of $Ho_{1-x}Er_xGa_2$ compounds.

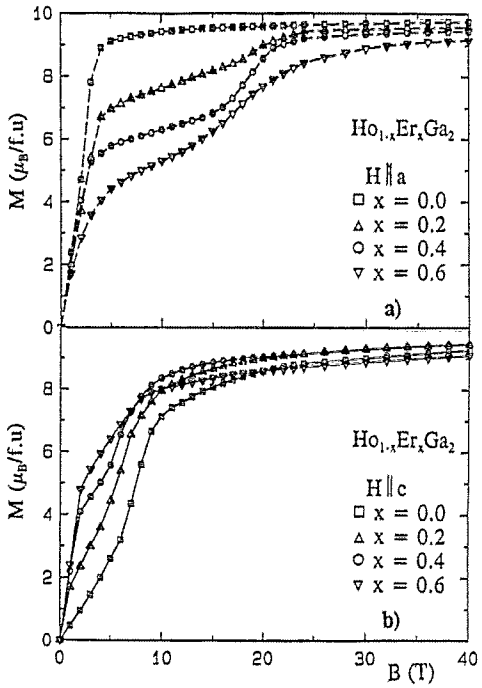

Fig. 3. The high-field magnetization at 1.6 K along the a (a) and c axis (b) of $Ho_{1-x}Er_xGa_2$ compounds.

In conclusion, additional high-field anomalies around 18–19 T along the a-axis are observed in $Ho_{1-x}Er_xGa_2$ compounds. T_N is found to depend nonlinearly on Er content. The results suggest that there is no interaction between the orthogonally directed magnetic moments of the Er and Ho atoms, and each subsystem orders independently at different temperatures.

Acknowledgements: Work has been partly supported by the Polish Scientific Committee (KBN).

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