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FIELD-INDUCED MAGNETIZATION IN Ho$_{0.53}$Er$_{0.47}$Co$_{3.04}$Ni$_{1.95}$

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Abstract. The magnetization process of Ho$_{0.53}$Er$_{0.47}$Co$_{3.04}$Ni$_{1.95}$ single crystals was investigated in a field up to 10 T from 4.2 to 300 K as a function of the angle between the c-axis and the magnetic field. The magnetic spin structure is interpreted in a crystal-field-with-exchange-field model.

Introduction

The mixed compounds Ho$_{1-x}$Er$_x$Co$_{3+y}$Ni$_2$ exhibit complicated behaviour of magnetocrystalline anisotropy [1]. Therefore, it would be interesting to investigate the magnetic moment as a function of the applied field. Magnetization measurements on the Ho$_{0.53}$Er$_{0.47}$Co$_{3.04}$Ni$_{1.95}$ single crystals made it possible to attempt a more complete analysis in terms of the crystal field and exchange field in this compound.

Experimental and results

The measurements of the magnetic moment were carried out with a string magnetometer in the applied field up to 10 T in the temperature range of 4.2–300 K. The magnetization $M_o$, $M_a$ and $M$ was measured along the c-, a-axis and for a single crystal rotating freely in the field, respectively. (There was no difference in magnetization along the a- and b-axis.) Isotherms of the magnetization at 4.2, 40 and 77 K are shown in figure 1. It should be noted that at low temperatures the magnetization $M_a$ approaches the smallest values whereas they are the highest at temperatures above $T_{	ext{com}}$. Magnetization curve $M_a$ increases distinctly with an increase in the magnetic field at low temperatures and overlaps the magnetization curve $M$ at 77 K in magnetic field of 1.3 T. It is clear that the ferrimagnetic moment of the studied crystal rotates with increase in temperature from a cone to c-axis. The tilt angle of the resultant moment from the c-axis can be calculated from $\cos \theta = \frac{M_o}{M_0}$, where $M_o$, $M_0$ are the spontaneous magnetizations determined by extrapolating to zero field in $M^2$ versus $B / M$ plots. The value of the tilt angle at 4.2 K is calculated as $30^\circ$. On the other hand, the tilt angle can also be obtained by $\tan \theta = \frac{M_a}{M}$. It is noteworthy that the value of tilt angle computed from arctan $(M_a / M_e)$ at magnetic field of 1.8 T is $49^\circ$ at 4.2 K and corresponds to that derived from torque curves recorded for ac-plane in the whole temperature region of the spin reorientation [1].

Analysis and discussion

An attempt has been made to treat the magnetic spin structure of the studied crystal in terms of a crystal field and exchange field confined to the $x-z$ plane using a Hamiltonian of the form:

$$\mathcal{H} = B^0_oO^0_o + 2(g - 1) \times \mu_B (J_z |H_{ex}| \cos \theta + J_e |H_{ex}| \sin \theta)$$

(1)

(The details of this model are described in [2].) The magnetic moments of the crystal field state can be calculated as in [3] from expressions:

$$\mu_\parallel = 1 / J \sum_{M=-J}^J M a_M^2, \quad \mu_\perp = 1 / J (\Gamma |J_\Sigma| \Gamma)$$

(2a)

$$\mu = (\mu_\parallel + \mu_\perp)^{1/2}, \quad \mu (\mu_B) = \mu g J$$

(2b)

where the crystal field ground state $|\Gamma\rangle$ is a linear combination of $M_J$ states for a given angle $\theta$.

Angular dependence of the total ground state energy (including the anisotropy energy of 3d sublattice [2]) obtained with parameters $B^0_o$ (Ho) = 0.34 K, $B^0_e$ (Er) = −0.372 K, $H_{ex}$ = 128 T, $K (3d) = 2.4 \times$
$10^6$ J/m$^3$, indicated a cone angle equal 30°. Then the ground state moments of Ho and Er ions are 8.8 and 9.5 $\mu_B$, respectively. Calculations of $\mu_\parallel$ and $\mu_\perp$ enable the forming of an arrangement of magnetic moments in Ho$_{0.53}$Er$_{0.47}$Co$_{3.04}$Ni$_{1.95}$ which is noncollinear (Fig. 2).

![Diagram](image)

Fig. 2. – Arrangement of magnetic moments in Ho$_{0.53}$Er$_{0.47}$Co$_{3.04}$Ni$_{1.95}$ predicted by CEF model.

Nevertheless assuming that the Er and Ho ions statistically occupy position 1a in CaCu-type structure it can be considered that moment 3d is antiparallel coupled with the average magnetic moment of the rare earth sublattice (9.0 $\mu_B$). The resultant moment observed in experiment ($M_0(4.2 \text{ K}) = 3.7 \mu_B$) fulfills the relation: $M_0 = M(R) - M(3d)$ for $\mu_{Co} = 1.77 \mu_B$. Value $\mu_{Co}$ calculated in this way is in good agreement with result obtained from neutron studies on HoCo$_5$ [4].

Futhermore the large high-field susceptibility, particularly along the c-axis, can be understandable for the system presented in figure 2. In general the external field causes deviations of the sublattice moments due to the interplay between the sublattice anisotropies and the intersublattice exchange energies [5, 6]. The induced canting is a function of the value and direction of the applied field ($\sim B \sin (c, B)$). Therefore the canting is most clearly seen in magnetization $M_\alpha$ at an angle of about 60° to the easy direction. The applied field influences the magnetization curves more as temperature approaches $T_{com}$.

With temperature increase the role of the rare earth sublattice decreases but Er contribution decreases faster than the Ho one. In result of this the easy direction magnetization approaches the easy base plane near the compensation point and then moves towards the c-axis due to the Co anisotropy energy.

Concluding it seems that the arrangement of magnetic moments in Ho$_{0.53}$Er$_{0.47}$Co$_{3.04}$Ni$_{1.95}$ predicted by the crystal-field-with-exchange-field model is consistent with the magnetic measurements.

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