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MAGNETOCRYSTALLINE ANISOTROPY OF $\text{Tb}_{1.1}(\text{FeCo})_{11}\text{Ti}$

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The $\text{Tb}_{1.1}\text{Fe}_{11-x}\text{Co}_x\text{Ti}$ ($x = 0, 1, 2, 3, 4$) compounds with the ThMn_{12} -type structure were studied by using the torque and magnetization measurements in order to investigate temperature and composition behavior of the magnetocrystalline anisotropy. The $\text{Tb}_{1.1}(\text{FeCo})_{11}\text{Ti}$ single crystals demonstrated spin reorientation transition from easy axis to easy plane with the decrease in temperature. The substitution of Co for Fe produces an enhancement of the Curie temperatures, decreases temperatures of spin reorientation transition and appearance of canted structure.

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1. Introduction

Recently research efforts of many scientific groups were focused on the Fe-rich compounds of the type RFe_{11}Ti (R = rare earth) which crystallize in the body-centered tetragonal ThMn_{12} structure, in view of their interest as permanent magnetic materials [1–10].

The present investigation deals with the effect of Co substitution in $3d$ -sublattice on the magnetic behavior and on the magnetic ordering temperature of $\text{Tb}_{1.1}(\text{FeCo})_{11}\text{Ti}$ single crystals.

2. Experiment and results

The alloys $\text{Tb}_{1.1}(\text{FeCo})_{11}\text{Ti}$ were prepared by induction melting of constituent elements in argon atmosphere (Tb and Ti with purity 99.9% and Fe with purity of 99.99%). To ensure homogeneity the obtained ingots were crushed and remelted in vacuum. X-ray diffraction was employed to analyze these alloys for their single phase character. The single crystals were extracted from the ingot of these alloys and oriented by the conventional back Laue reflection method. Magnetocrystalline anisotropy of these samples was investigated by means of torsion and magnetization measurements.

For tetragonal crystal the magnetic free energy is expressed as

$$E_a = K_1 \sin^2 \theta + K_2 \sin^4 \theta + K_3 \sin^4 \theta \cos^4 \varphi - M_s H \cos(\theta - \varphi),$$

where K_1 , K_2 , and K_3 are the anisotropy constants. θ and φ are the angles between the c -axis and the magnetization vector M and magnetic field H respectively; φ is the angle between the projection M on the basal plane and the symmetry axis [100].

To define the values of these anisotropy constants the torque curves in the (110) and (100) planes were measured for single crystals $\text{Tb}_{1.1}(\text{FeCo})_{11}\text{Ti}$ with different cobalt concentration. The experimental torque curves were obtained in the temperature range 77–750 K and in magnetic field up to 1.2 T. These torque curves $L(\varphi)$ together with the curves of the anisotropic part of the free energy $E(\varphi)$ in the plane (110) permit to determine the position of easy magnetization direction (EMD), which coincides with the minimum in the $E(\varphi)$ curves. See, for example, Fig. 1 where these curves are presented for $\text{Tb}_{1.1}\text{Fe}_{11}\text{Ti}$ at various temperatures.

Fig. 1. Torque curves and angular dependence of the free energy for $\text{Tb}_{1.1}\text{Fe}_{11}\text{Ti}$ at various temperatures.

Fig. 2. The temperature dependence of the anisotropy constants K_1 , K_2 , and K_3 for $\text{Tb}_{1.1}\text{Fe}_{11}\text{Ti}$ (a) and for $\text{Tb}_{1.1}\text{Fe}_9\text{Co}_2\text{Ti}$ (b).

EMD is positioned in basal plane along the $[110]$ axis at all temperatures up to 405 K. At this temperature in the $\text{Tb}_{1.1}\text{Fe}_{11}\text{Ti}$ single crystal a spin-reorientation transition (SRT) from easy plane to easy axis is observed. At temperature greater than 405 K and up to Curie temperature magnetocrystalline anisotropy becomes very small. The temperature dependences of the anisotropy constants were determined using least-squares fitting for the corrected experimental torque curves in the vicinity of the EMD in the (110) and (100) planes. For $\text{Tb}_{1.1}\text{Fe}_{11}\text{Ti}$ constant K_1 is negative at low temperatures and becomes equal to 0 at the $T_{\text{SRT}} = 405$ K, constant K_2 also is negative at the same temperature (Fig. 2a). For the $\text{Tb}_{1.1}\text{Fe}_9\text{Co}_2\text{Ti}$ single crystal constants K_1 and K_2 pass through 0 at $T_{\text{SRT}} = 325$ K and are negative below this temperature (Fig. 2b). The growth Co concentration in the $\text{Tb}_{1.1}(\text{FeCo})_{11}\text{Ti}$ single crystals leads to a decrease in the SRT temperature and to the appearance of the conical structure.

3. Discussion

The appearance of the phase transition can be explained by the temperature dependent competition between the rare-earth sublattice anisotropy and the transition metal (Fe Co) sublattice anisotropy. In these compounds Tb with negative second order Stevens coefficient ($\alpha_J < 0$) favors planar rare-earth sublattice anisotropy while Fe and Co sublattice favor uniaxial and planar anisotropy respectively, and hence SRT could be expected. The type of magnetic ordering of these compounds is presented in magnetic $T-x$ phase diagram (Fig. 3), which was constructed on the basis of the experimental results. It is worth noting that the very small increase in Tb in these compounds strongly affects their magnetic anisotropy as compared with the $\text{Tb}(\text{FeCo})_{11}\text{Ti}$ single crystal [11]. It can be assumed that this effect results from a complex modification of the crystal field caused by the Tb-ion. Further work is in progress to understand this behavior of these compounds.

Fig. 3. Magnetic $T-x$ phase diagram for $\text{Tb}_{1.1}\text{Fe}_{11-x}\text{Co}_x\text{Ti}$. The concentration dependence of the Curie temperature at $B = 1.25$ T.

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