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Magnetostriction and magnetic anisotropy in $\text{TbFe}_{11}\text{TiH}_x$ ($x=0, 1$) single crystals

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Abstract

Single crystals of $\text{TbFe}_{11}\text{Ti}$ and its hydride with tetragonal ThMn_{12} -type structure were obtained. Magnetostriction measurements have been made on $\text{TbFe}_{11}\text{TiH}_x$ ($x=0, 1$) single crystals by the applied strain gauge method in the temperature range from 77 to 400 K and in magnetic fields up to 13 kOe. Magnetization measurement along the main crystallographic directions of the tetragonal structure have been performed on $\text{RFe}_{11}\text{TiH}_x$ ($x=0, 1$) single crystals in applied high magnetic fields up to 120 kOe in the temperature range from 4.2 to 300 K. It was concluded that hydrogenation results in an increase in rare-earth anisotropy that leads to the disappearance of the spin-reorientation transition in the $\text{TbFe}_{11}\text{TiH}$ single crystal. Hydrogenation lead to a change in sign of the magnetic anisotropy constant K_3 and the magnetostriction constant $\lambda_2^{\alpha,2}$. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Rare earth compounds; Transition metal compounds; Hydrogen absorbing materials; Anisotropy; Magnetic measurements

1. Introduction

It is well known that the most reliable data of magnetostriction and magnetic anisotropy in RFe_{11}Ti (R — rare-earth metal) intermetallic compounds can be obtained mainly from magnetic measurements of single-crystal samples [1–5]. Absorption of hydrogen gas leads to marked changes in the main magnetic properties of these compounds [6–8]. Up until now, no single crystals of the hydrogen containing compounds were available. In this paper, we have studied the effect of the interstitial hydrogen on the magnetostriction, magnetization and magnetic anisotropy on single crystals of $\text{TbFe}_{11}\text{Ti}$ as a continuation of our previous work [9,10].

2. Experimental methods

The $\text{TbFe}_{11}\text{Ti}$ compound was prepared by induction melting under argon atmosphere of the constituent ele-

ments (Tb, Fe, Ti) of at least 99.95 wt% purity. Details of the single crystal preparation and hydrogenation have been described earlier in Ref. [9]. The amount of absorbed hydrogen in the samples was estimated using a volumetric method and was close to one hydrogen atom per formula unit ($\delta \leq 0.05$ at.H/f.u). Magnetostriction measurements have been made on $\text{TbFe}_{11}\text{TiH}_x$ ($x=0, 1$) single crystals by the applied strain gauge method in the temperature range from 77 to 400 K and magnetic fields up to 13 kOe. Magnetization measurement along the main crystallographic directions of the tetragonal structure have been performed on $\text{RFe}_{11}\text{TiH}_x$ ($x=0, 1$) single crystals in applied high magnetic fields up to 120 kOe in the temperature range from 4.2 to 300 K.

3. Results and discussion

Figs. 1 and 2 show the isotherms obtained from the magnetisation measurements at $T=4.2$ K for $\text{TbFe}_{11}\text{Ti}$ and its hydride, respectively. The easy magnetisation direction (EMD) coincides with [100] axis for $\text{TbFe}_{11}\text{Ti}$ (see Fig. 1). A large magnetic anisotropy within the (001) plane is

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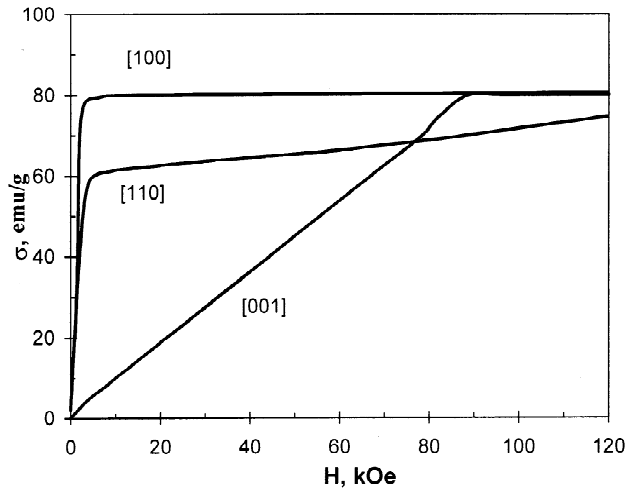


Fig. 1. Isothermal magnetization curves at $T=4.2$ K on a single crystal of $\text{TbFe}_{11}\text{Ti}$ for magnetic fields applied along the main symmetry directions: [100], [110], [001].

present. The magnetic field needed to saturate the magnetisation along the [001] axis is smaller than the one needed to saturate it along the [110] axis. As the temperature is increased a spin reorientation transition (SRT) occurs at about $T_{\text{SR}}=325$ K, where the easy direction changes from the [100] to the [001] axis. This SRT is of first order, from basal-plane anisotropy to uniaxial anisotropy without a cone range. This transition is a consequence of the competition of the planar Tb sublattice anisotropy and the uniaxial Fe sublattice anisotropy, the former being dominant at lower temperatures and the latter being dominant at higher temperatures. Our results for $\text{TbFe}_{11}\text{Ti}$ agree well with the data obtained earlier [2,6].

Drastic changes in the magnetic anisotropy are observed after hydrogenation. First of all, in the $\text{TbFe}_{11}\text{TiH}$ single crystal the EMD lies along the [110] direction at $T=4.2$ K.

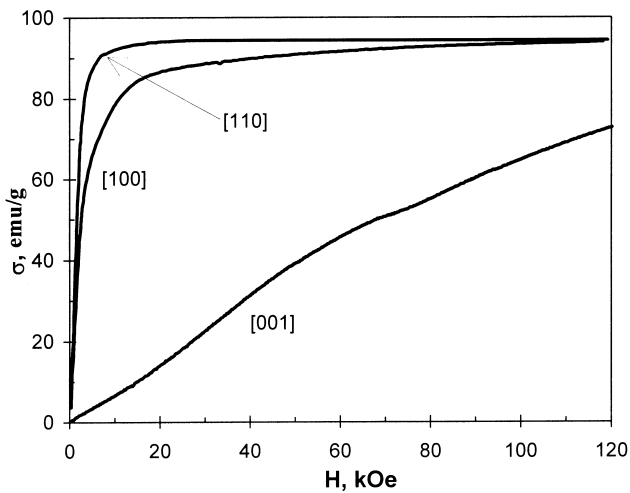


Fig. 2. Isothermal magnetization curves at $T=4.2$ K on a single crystal of $\text{TbFe}_{11}\text{TiH}$ for magnetic fields applied along the main symmetry directions: [100], [110], [001].

Secondly, the magnetic anisotropy within the (001) plane has decreased. Thirdly, the magnetisation curve measured along the [001] axis has not achieved saturation even in magnetic fields up to 120 kOe. Besides, it was observed that the hydrogenation leads to the disappearance of the SRT in $\text{TbFe}_{11}\text{TiH}$ [9]. The net magnetisation lies in the basal plane and is directed along the [110] axis in the whole temperature range. In our case, where the anisotropy within the basal plane can not be neglected, i.e. $K_3 \neq 0$, it is possible to assert that the anisotropy within the basal plane (K_3 constant) changes its sign after hydrogenation.

In order to determine the character of the Tb sublattice magnetic moment rotations under an applied external magnetic field $H \parallel [001]$ -axis, the temperature dependence of the longitudinal magnetostriction λ_{\parallel} was measured in $H=13$ kOe (see Fig. 3). Preliminarily, the magnetostriction curves of tetragonal YFe_{11}Ti and $\text{LuFe}_{11}\text{Ti}$ single crystals have been measured. We estimated that the contribution to the magnetostriction from the iron sublattice is one order of magnitude lower than that for the rare earth sublattice. The approximate value and, mainly, sign of the single crystal magnetostriction constant $\lambda_2^{\alpha,2}$ can be determined from these measurements.

At low temperatures (from 100 to 150 K) λ_{\parallel} is constant as seen in Fig. 3. In the range from 180 to 240 K, magnetostriction rises sharply with increasing temperature. λ_{\parallel} passes through a maximum around $T=300$ K and then drops rapidly. Our results can be interpreted as follows. In the low-temperature range, the longitudinal magnetostriction is small because the magnetic moment of the $\text{TbFe}_{11}\text{Ti}$ compound lies in the basal plane, and the magnetic field $H=13$ kOe applied along the [001] axis is not high enough to bring it out of the plane. The build-up of the c -axis magnetostriction with increasing temperature implies that, as the temperature approaches T_{SR} , the magnetic anisotropy decreases and becomes insignificant near the SRT temperature. In this case, the magnetic field applied along the [001] axis is capable of swinging the

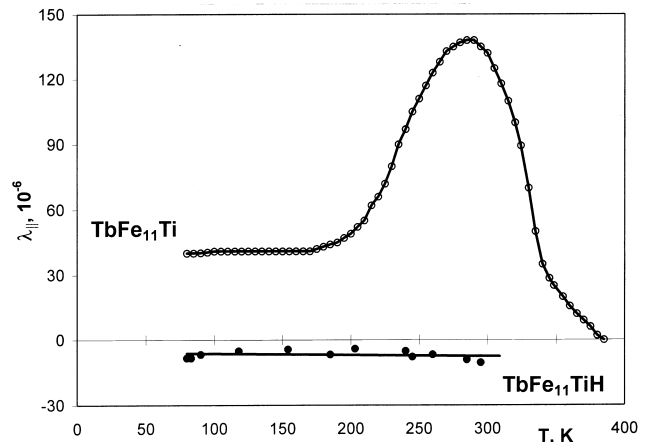


Fig. 3. Temperature dependence of the longitudinal magnetostriction of $\text{TbFe}_{11}\text{Ti}$ and its hydride at $H=13$ kOe.

magnetic moment away from the basal plane towards the [001] axis. In the temperature range from 300 to 380 K, λ_{\parallel} drops abruptly, presumably because the magnetic moments align along the [001] axis, and the subsequent rotation of the magnetic moment of the sample makes only a small contribution to the magnetostriction. The magnetostriction related to displacement of domain boundaries can be neglected. This contribution is insignificant in uniaxial magnetic materials. In $\text{TbFe}_{11}\text{TiH}$ the longitudinal magnetostriction decreases in value, becoming negative, and is almost temperature-independent. Hydrogenation leads to a sign change of the $\lambda_2^{\alpha,2}$ magnetostriction constant.

4. Conclusion

Both the magnetostriction and the magnetic anisotropy depend strongly on the values of the electric fields at the site of the R -ions. The interstitial H atoms occupy the 2b sites adjacent to the rare earth, creating a change of crystal field. The incorporation of H leads to an expansion of the temperature range in which the magnetic anisotropy of the rare-earth sublattice dominates over that of the iron sublattice. The spin reorientation transition disappears after hydrogenation. Hydrogenation leads to changes in sign both of the magnetic anisotropy constant K_3 and the magnetostriction constant $\lambda_2^{\alpha,2}$.

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