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Magnetostriction of $Ce_xTb_{1-x}Fe_2$ compounds

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Abstract

In this paper, the magnetostriction of $Ce_xTb_{1-x}Fe_2$ compounds was investigated using a standard strain gauge technique, and the intrinsic magnetostriction of $Ce_xTb_{1-x}Fe_2$ compounds was derived from fitting the (4 4 0) peak of the X-ray diffraction pattern. It is found that the magnetostriction of $Ce_xTb_{1-x}Fe_2$ compounds decreases slowly with increasing Ce content at low Ce content, while decreases sharply at high Ce content. X-ray diffraction analysis shows that the intrinsic magnetostriction decreases with the Ce concentration increasing in $Ce_xTb_{1-x}Fe_2$ compounds, and the Ce ion contributes to the magnetostriction.

Keywords: $Ce_xTb_{1-x}Fe_2$; Magnetostriction; Laves-phase; Structure; X-ray diffraction

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1. Introduction

The cubic Laves-phase compounds RFe_2 (where R = rare earth) have attracted a great deal of attention because of their large magnetostriction at room temperature [1–4]. Among them, the compounds of $TbFe_2$ and $SmFe_2$ are well known as the giant magnetostrictive materials. However, according to the single-ion model, $CeFe_2$ and $PrFe_2$ compounds have larger magnetostriction than $TbFe_2$ and $SmFe_2$ at 0 K [5]. But the magnetostriction of $CeFe_2$ only shows 60 ppm at 4.2 K. The great difference between theory and experiment is due to the mix-valence behavior of Ce ions. Many studies have been done on the compounds with Ce. The experimental results show that the Ce ion has the transition tendency from localized state to delocalized state in some intermetallics [6–8]. In order to identify the contribution of Ce ion to the magnetostriction, the magnetostriction and intrinsic magnetostriction λ_{111} of $Ce_xTb_{1-x}Fe_2$ compounds were investigated in this work.

2. Experiment

The ingots of $Ce_xTb_{1-x}Fe_2$ ($x = 0.0$–0.8) were prepared by arc melting the appropriate amounts of Fe (purity better than 99.9 wt.%) and rare earth (99.95 wt.%) under a purified-argon atmosphere. The as-cast ingots were wrapped in tantalum foils and vacuum annealed for a week at 850 °C in sealed quartz capsules.

X-ray diffraction measurements on powder samples were performed using Cu Kα radiation to identify the phase purity. The magnetostriction ($\Delta\lambda = \lambda_{//} - \lambda_{\perp}$) was measured at room temperature by a standard strain gauge technique. The intrinsic magnetostriction of the compounds was derived from fitting the (4 4 0) peak of the X-ray diffraction pattern, and calculated from $\lambda_{1\,1\,1}=(1-\sin\theta_2)/\sin\theta_1$, where θ_1 and θ_2 are the Bragg angles.

3. Results and discussion

X-ray patterns for $Ce_xTb_{1-x}Fe_2$ with the different Ce concentrations are shown in Fig. 1. It can be seen that the cubic Laves ($MgCu_2$) structure is maintained for $Ce_xTb_{1-x}Fe_2$ throughout the alloy series.

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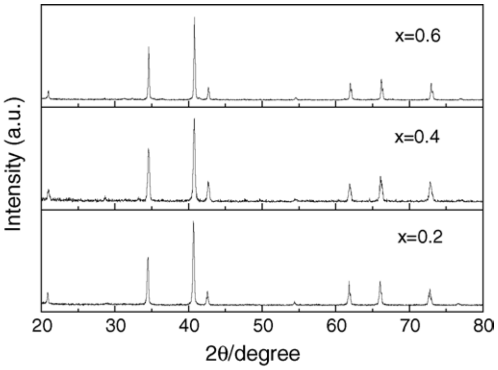

Fig. 1. X-ray patterns for $Ce_xTb_{1-x}Fe_2$ with the different Ce concentration.

Fig. 2 shows the magnetic-field dependence of the magnetostriction for $Ce_xTb_{1-x}Fe_2$ compounds at room temperature. It can be seen from Fig. 2 that the magnetostriction of $Ce_xTb_{1-x}Fe_2$ compounds decreases slowly with increasing Ce content when $x \leqslant 0.4$, while decreases sharply when $x > 0.4$. It can be attributed to the change of Ce ion valence toward trivalence [8].

Because the powder of the $Ce_xTb_{1-x}Fe_2$ compounds with high Ce concentration is oxygenated easily in the atmosphere, only the (4 4 0) X-ray reflection of the compounds with $x < 0.4$ were obtained in our study. Fig. 3 shows the observed and calculated profiles for the (4 4 0) X-ray reflection of $Ce_xTb_{1-x}Fe_2$ alloys. The two broken lines represent two separate diffracted $K_{\alpha 1 \alpha 2}$ profiles reflected from two separate lattices. It can be seen that the intrinsic magnetostriction $\lambda_{1\,1\,1}$ of $Ce_xTb_{1-x}Fe_2$ compounds decrease from 2455 ($x = 0.1$) to 1815 ($x = 0.3$) with increasing Ce concentration. Many experiments show that the intrinsic magnetostriction $\lambda_{1\,1\,1}$ of RFe_2 is provided by R ions and the intrinsic magnetostriction $\lambda_{1\,1\,1}$ of polycrystalline $TbFe_2$ is 2629 ppm. Assuming that the intrinsic magnetostriction $\lambda_{1\,1\,1}$ of $TbFe_2$ is directly proportion to Tb concentration, the magnetostriction provided by Tb ions in $Ce_xTb_{1-x}Fe_2$ will also decrease by 10% (263 ppm) when Tb concentrations decrease by 10%, and Tb ions contribute 2366 ppm to the magnetostriction of $Ce_{0.1}Tb_{0.9}Fe_2$ compound. Whereas Fig. 3 shows that the intrinsic magnetostriction $\lambda_{1\,1\,1}$ of $Ce_{0.1}Tb_{0.9}Fe_2$ compound

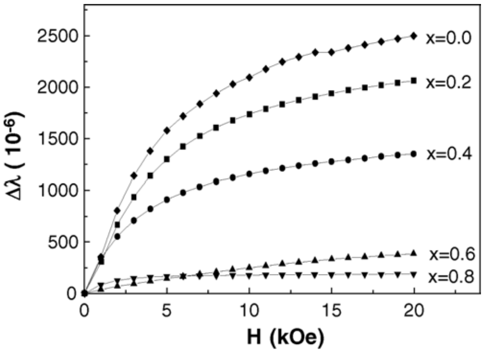

Fig. 2. Magnetostriction of $Ce_xTb_{1-x}Fe_2$ as function of magnetic field at room temperature.

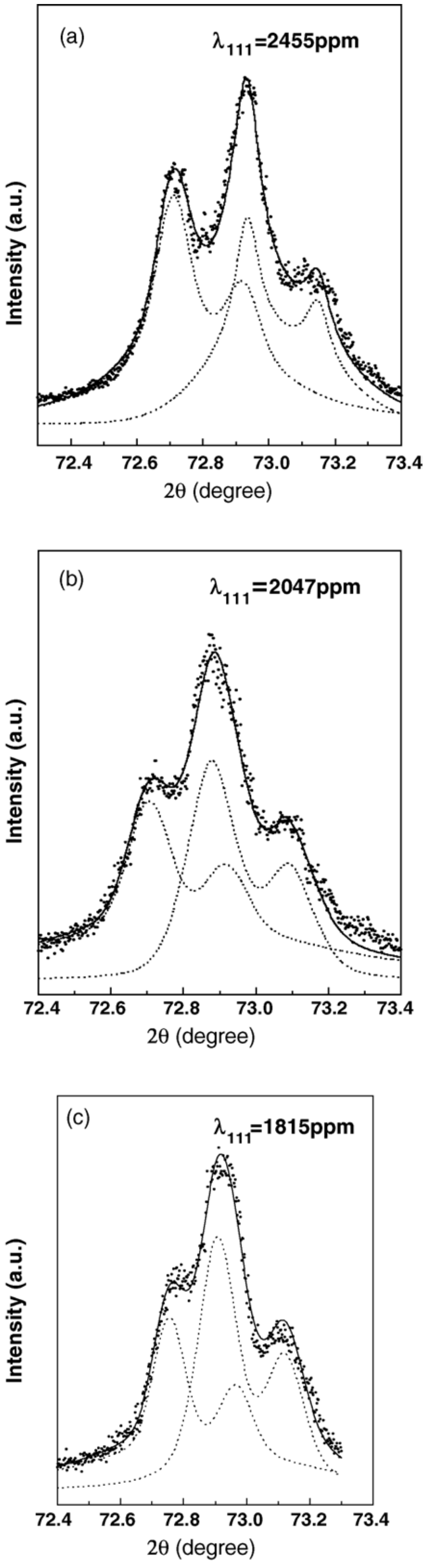

Fig. 3. Observed (square) and calculated (solid line) profiles for the (4 4 0) X-ray reflection of $Ce_xTb_{1-x}Fe_2$ compounds. (a) $x = 0.1$ (b) $x = 0.2$ (c) $x = 0.3$.

is 2455 ppm, so it is Ce ions that provide 90 ppm for the magnetostriction of $Ce_{0.1}Tb_{0.9}Fe_2$ compound. The magnetostriction of $CeFe_2$ will be 900 ppm by linearly extrapolating from the magnetostriction value of $Ce_{0.1}Tb_{0.9}Fe_2$ compound. However, this magnetostriction value (900 ppm) of $CeFe_2$ is smaller than the value from single-ion model. It is ascribed to the fact that the Ce ion has the tendency to the localized state, but the Ce valence does not reach +3 in $Ce_xTb_{1-x}Fe_2$ compounds [8]. Although this value 900 ppm is smaller than the value from single-ion model, it can be confirmed that the Ce ions really contribute to the magnetostriction of $Ce_xTb_{1-x}Fe_2$ compounds.

4. Conclusion

The $Ce_xTb_{1-x}Fe_2$ compounds with Laves-phase structure are synthesized. The magnetostriction and intrinsic magnetostriction $\lambda_{1\,1\,1}$ of $Ce_xTb_{1-x}Fe_2$ compounds decrease with increasing Ce concentration, while it can be concluded that Ce ions really contribute to the magnetostriction in $Ce_xTb_{1-x}Fe_2$ compounds.

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