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Journal of Alloys and Compounds 216 (1994) 85–87

Journal of ALLOYS AND COMPOUNDS

The effects of boron on the magnetostrictive properties of $Tb_{0.27}Dy_{0.73}Fe_2$

Lei Wu, Wenshan Zhan, Xicheng Chen, Xishen Chen

Institute of Physics, Chinese Academy of Sciences, Beijing 100080, People's Republic of China

Received 1 April 1994

Abstract

The magnetostrictive properties and microstructure of $Tb_{0.27}Dy_{0.73}Fe_2B_x$ ($x=0$, 0.05, 0.1, 0.15, 0.2) have been investigated. Measurement of magnetic properties, X-ray diffraction and magnetostriction were made on $Tb_{0.27}Dy_{0.73}Fe_2B_x$ polycrystalline samples prepared by the arc melting technique. With the increase of boron context x, the iron-rich phase which leads to the detriment of magnetostrictive properties decreases obviously. The matrix phase of these alloys also has an $MgCu_2$ structure type. The lattice constant and Curie transition temperature change only slightly. Doping of boron in the $Tb_{0.27}Dy_{0.73}Fe_2$ alloy can restrain the emergence of an iron-rich phase. The peritectic action point either shifts slightly or the peritectic action is promoted by boron.

Keywords: Magnetostrictive properties; Boron; X-ray diffraction; Arc melting

1. Introduction

In recent years various studies have been made on the material $Tb_{0.27}Dy_{0.73}Fe_2$. The cubic laves phase ($MgCu_2$) compounds for rare-earth with iron (RFe_2) are well known for their giant magnetostriction [1]. As a result of the strong exchange interactions, coupled with the large concentration of rare-earth ion, these compounds have the interesting magnetostrictive and anisotropic properties of the rare earth element, which were available previously only at cryogenic temperature, to room temperature. The huge magnetostriction was attributed to the large spin orbit interaction between the electron spin and the specially anisotropic 4f charge cloud. In the effects to decrease the anisotropy energy many pseudobinary compounds with compensated anisotropy have been reported [2]. One of these compounds, $Tb_{0.27}Dy_{0.73}Fe_2$, exhibits a maximum proportion of magnetostriction to anisotropy, λ/K_1, which is ideal for use in many transducer applications. The ternary alloy of $Tb_{0.27}Dy_{0.73}Fe_2$ is expected to melt peritectically because both $DyFe_2$ and $TbFe_2$ are reported [3,4] to melt peritectically. For this reason, it has proven difficult to prepare large defect free single crystals of Terfenol-D. Any deviation from these compositions will result in the appearance of intergrain rare-earth phase or intragrain RFe_3. The existence of such second phases is detrimental to the magnetostriction of the materials, especially at low magnetic field. The brittleness of $Tb_{0.27}Dy_{0.73}Fe_x$ is a strong function of Fe stoichiometry. When $x=2$, the sample became more brittle and less magnetostrictive, because of the residue of RFe_3. Previously, attempts were made to improve the strength and the toughness of the material by control of the stoichiometry. If x is reduced to values of less than 2.0, it is found that increasing volume fraction of the rare-earth metal phase is produced in the Terfenol-D matrix by the solidification process at lower Fe concentrations. In the course of this work, we used boron dopes in $Tb_{0.27}Dy_{0.73}Fe_2$ in order to develop a new intermetallic compound system and to improve the strength and magnetostrictive properties.

2. Experimental details

The reagents used in these preparations were 99.9% rare-earth ingot, 99.9% iron rod and FeB alloy (14 wt.% for B, 86 wt.% for Fe). During our work, melts of initial composition $Tb_{0.27}Dy_{0.73}Fe_2B_x$ for the values $x=0$, 0.05, 0.1, 0.15 and 0.2 were prepared. The rare-earths, Fe and FeB alloy were weighted in the desired ratio in amounts sufficient to yield a melt of 15 to 20 grams total mass. As a result of the volatility of rare-earth, the starting compositions were taken at 1% richer

SSDI 0925-8388(94)01255-G

in rare-earth in order to obtain the correct stoichiometry. The metals were initially alloyed together by arc melting in a water cooled copper crucible under a purified argon atmosphere, and the button produced was turned over and remelted three times in order to ensure homogenization. The ingots obtained after melting were sealed in quartz tube at about 10^{-5} Pa, and annealed at 1000 °C for a week.

The samples were cut into slips of about 6 mm×6 mm×3 mm and examined by scanning electron microscopy (SEM). Vilella's reagent (1 g picric acid in 5 ml HCl plus 95 ml methanol) was used to determine grain size and distribution. The magnetostrictive measurement was made by the strain gauge method in an applied field of up to 2×10^4 Oe at room temperature. Phase analysis was carried out by means of X-ray powder diffraction techniques with Co Kα radiation. The Curies point shift was examined by means of a Faraday balance.

3. Results and discussion

Polished samples were examined by SEM. Fig. 1 shows the SEM image of $Tb_{0.27}Dy_{0.73}Fe_2B_x$ ($x=0$, 0.05, 0.1, 0.15, 0.2). Where the dark microconstituent is the rich-iron phase. It is obvious that the iron-rich phase (RFe_3) decreases with increase of boron content x. When $x=0.2$, almost no iron-rich phase appears. These results were also confirmed by X-ray diffraction.

Figure 2 shows the results of magnetostrictive measurements by means of the strain gauge method. The magnetostriction of $Tb_{0.27}Dy_{0.73}Fe_2B_x$ increases with increasing x content firstly, then decreases slightly. The whole magnetostriction change is rather modest.

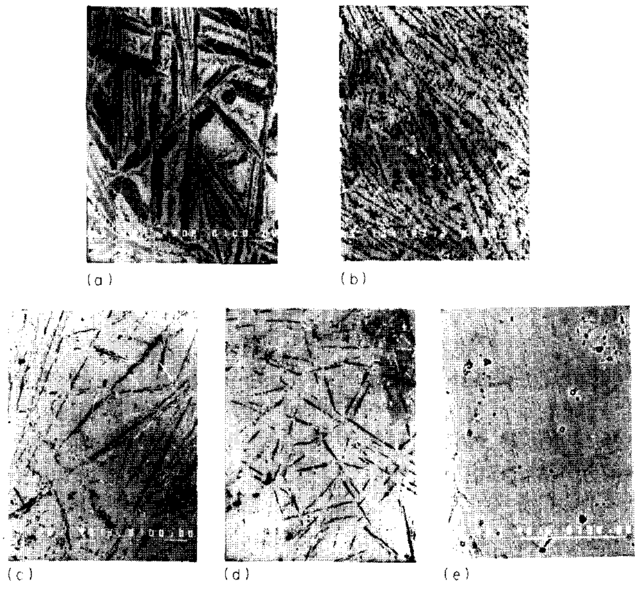

Fig. 1. SEM image of $Tb_{0.27}Dy_{0.73}Fe_2B_x$. (a) $x=0$, (b) $x=0.05$, (c) $x=0.1$, (d) $x=0.15$, (e) $x=0.2$.

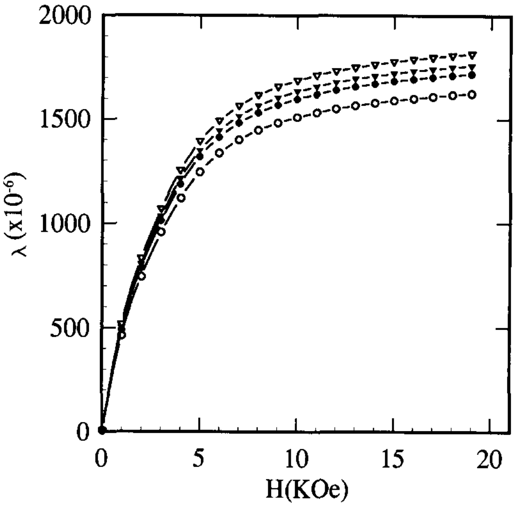

Fig. 2. Magnetostriction of $Tb_{0.27}Dy_{0.73}Fe_2B_x$. ○, $x=0$; ●, $x=0.1$; ▽, $x=0.15$; ▼, $x=0.2$.

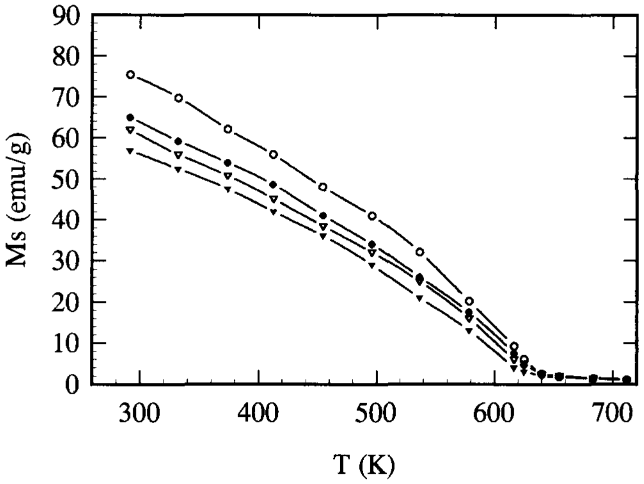

Fig. 3. M–T curves of $Tb_{0.27}Dy_{0.73}Fe_2B_x$ measured in a field of 1.2 T. ○, $x=0$; ●, $x=0.05$; ▽, $x=0.1$; ▼, $x=0.2$.

Figure 3 shows the M–T curves of $Tb_{0.27}Dy_{0.73}Fe_2B_x$ measured in a field of 1.2 T. The ordering temperature T_C decreases slightly. Because the lattice constant varied slightly after boron doping, the distance between the Fe ion changed slightly. This can be affirmed by (422) power diffraction peak datum. The ordering temperature is affected by the lattice constant changing.

4. Conclusion

We believe that boron doping in $Tb_{0.27}Dy_{0.73}Fe_2$ can restrain the emergence of the iron-rich phase. It is possible that boron leads to a substantial increase of the peritectic temperature so that $Tb_{0.27}Dy_{0.73}Fe_2B_x$ is formed directly. It is a significant result for obtaining the single phase Terfenol material.

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