ELSEVIER

Journal of Alloys and Compounds 452 (2008) 419–420

Journal of ALLOYS AND COMPOUNDS

www.elsevier.com/locate/jallcom

Atomic vacancy defect in ⟨1 1 0⟩ oriented TbDyFe alloy and its effect on the magnetostrictions

X.X. Gao, M.C. Zhang *, H.J. Tang, J. Zhu, S.Z. Zhou

State Key Laboratory for Advanced Metals and materials, University of Science and Technology Beijing, Beijing 100083, China

Received 25 September 2006; received in revised form 9 November 2006; accepted 9 November 2006
Available online 12 December 2006

Abstract

The atomic vacancies of ⟨1 1 0⟩ oriented TbDyFe rods with different heat treatment have been investigated by the positron annihilation technique. It has been found that the concentration of atomic vacancy is the highest in the sample solidified directionally. However, the concentration of vacancy decreases sharply with increase of annealing temperature and reaches the minimum value of 154 ps at 1293 K. Magnetostriction measurement shows that reducing the concentration of vacancy is favorable to enhance magnetostrictive property of the alloy.

Keywords: ⟨1 1 0⟩ oriented TbDyFe alloy; Positron lifetime; Atomic vacancy; Magnetostriction

1. Introduction

The laves phase (Tb, Dy)Fe_2 compound has $MgCu_2$ structure type. Its magnetic easy axis is the ⟨1 1 1⟩ direction and the magnetostrictive strain along this direction is 16.6 times larger than that along ⟨1 0 0⟩ direction because of the highly anisotropic magnetostriction. So the preparation of defect-free single crystals with ⟨1 1 1⟩ orientation is ideal for getting a maximum magnetostrivtive strain. However, it takes a very slow growing rate to grow single crystal, which is not economical for products. Fortunately, Verhoeven et al. [1] and Clark et al. [2] report that the preferential growth direction of Tb–Dy–Fe crystal has been demonstrated as ⟨1 1 2⟩ direction. It is 19.5° deviated from ⟨1 1 1⟩ orientation and the magnetostriction λ_{112} equals to 94% λ_{111} along this direction. So the ⟨1 1 2⟩ axial aligned polycrystalline rod samples have batter magnetostrictive properties. In addition, Zhang et al. [3] find that the polycrystalline rod samples aligned with ⟨1 1 0⟩ direction has higher λ value under lower magnetic field. In order to further increase the megnetostriction of TbDyFe material, the heat treatment process is usually taken for the samples solidified directionally. The λ values are increased as much as 20–80% after the samples were heat-treated [4,5]. The effectiveness of heat treatment is obvious. Why the λ values enhance so much after they were heat-treated? What kind of microstructure is favorable for the λ of material? There is still no any detail report.

As we know, the atomic vacancy is a kind of micro-defect for material. How is the effect of vacancy defect on the magnetostrictive property? Up to now, the report that is involved with vacancy research in TbDyFe alloy has not been found yet. In this paper, positron lifetime measurements have been performed in The $Tb_{0.3}Dy_{0.7}Fe_{1.95}$ aligned rod samples annealed with different temperatures.

2. Experimental

The $Tb_{0.3}Dy_{0.7}Fe_{1.95}$ rod samples with ⟨1 1 0⟩ orientation, which have the dimension of φ 10.1 mm × 12.5 mm, were prepared by high temperature gradient directional solidification device. Subsequently these samples were heat-treated at 1123–1353 K for 4 h and air cooled to room temperature. The magnetostrictive strain λ was measured by means of a standard strain gauge technique in the magnetic fields up to 100 kA/m at room temperature. The vacancy defects of samples were analyzed by the positron annihilation technique. The positron source is ^{22}Na with a substrate of kapton thin film and its intensity is about 0.5×10^6 Bq. Positron lifetime measurements were carried out using a fast–slow coincidence system spectrometer with a time resolution of 190 ps (full-width at half-maximum). More than 10^6 total counts were accumulated for each spectrum. After subtracting the source component and background, the positron lifetime spectra were analyzed by the Positronfit-88 program and we obtained three lifetime components τ_1, τ_2, τ_3 and their relative intensities I_1, I_2, I_3, respectively. For metals and alloys, the long lifetime component τ_3 is assigned to positron annihilation in the source itself. So we take τ_1, τ_2, I_1, I_2 as the object

* Corresponding author. Tel.: +86 10 62333502; fax: +86 10 62333502.
E-mail address: mczhang@skl.ustb.edu.cn (M.C. Zhang).

0925-8388/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.jallcom.2006.11.038

for discussing. In this case, $I_1 + I_2 = 1$. $\bar{\tau}$ and κ were calculated by $\bar{\tau} = \sum_{i=1}^{n} I_i \tau_i$ and $\kappa = (1/\tau_f)((\bar{\tau} - \tau_f)/(\tau_d - \bar{\tau}))$.

3. Results and discussion

The experimental data of positron lifetimes and calculated $\bar{\tau}$ and τ_κ of samples with different heat treatment are shown in Table 1. τ_1 is the lifetime comes from the un-trapped positron and mono-vacancy, divacancy, vacancy-like defect and τ_2 is the lifetime comes from the vacancy clusters, which were agglomerated by several vacancies according to the values of the lifetime τ_2 for the samples in Table 1. I_1 and I_2 reflect the defect concentrations of τ_1 and τ_2, respectively. $\bar{\tau}$ is an average value of positron lifetime and it reflects the comprehensive information of defect in a sample. The more $\bar{\tau}$ value the more vacancy defect. κ is the positron trapping rate and it reflects the concentration of atomic vacancy. From Table 1 one can find that positron lifetime $\bar{\tau}$ of the sample solidified directionally is the longest, which indicates that the atomic vacancy is the most in the sample. Due to the fast cooling speed during the directional solidification process, there was not enough time for the vacancies to diffuse to the surface of sample and most of them were preserved. The atomic vacancy of alloy can be removed by annealing at suitable temperatures. From Table 1 it can be found that the vacancies were not removed much after the sample was annealed at 1123 K for 4 h, because the value of $\bar{\tau}$ is still higher. This indicates that the atomic vacancies of sample cannot be reduced effectively by annealing at this temperature. However, the value of $\bar{\tau}$ decreases sharply with increasing temperatures and reaches the minimum value of 154 ps at 1293 K. The tendency of κ value variation is the same with $\bar{\tau}$. It shows that the concentration of vacancy defect of the alloy was reduced to the lowest after the sample annealed at 1293 K. As the temperature was raised to 1353 K, both $\bar{\tau}$ and κ increased.

Like atoms diffuse in metals and alloys, atomic vacancy can be removed from the internal to the surface of alloy by diffusion process. The removal effectiveness of vacancies depends on the diffusion coefficient. However, the diffusion coefficient is related to the temperature. The suitable temperature provides enough diffusion activation energy for the vacancies and causes them to move. From the experimental results above, it is obvious that 1293 K is the best temperature for removing vacancies in the alloy.

Table 1
Experimental data of positron lifetimes and calculated $\bar{\tau}$ and κ of samples with different heat treatment (κ is the trapping rate of positrons trapped by defect)

Sample	τ_1 (ps)	τ_2 (ps)	I_1 (%)	I_2 (%)	$\bar{\tau}$ (ps)	κ (ns^{-1})
A1 (as cast)	169	410	66.17	33.83	251	1.17
A2 (1123 K)	144	400	64.20	35.80	236	1.59
A4 (1223 K)	134	349	86.05	13.95	164	0.64
A6 (1293 K)	134	373	91.59	8.41	154	0.41
A8 (1353 K)	132	343	86.90	13.10	160	0.60

Table 2
λ values of TDT-110 samples after heat treatment (λ_{40} and λ_{80} is the magnetostriction under applied magnetic field of 40 kA/m and 80 kA/m, respectively)

Sample	A1 (as cast)	A2 (1123 K)	A4 (1223 K)	A6 (1293 K)	A8 (1353 K)
λ_{40} (ppm)	697	681	760	1211	1064
λ_{80} (ppm)	1040	1024	1177	1576	1420

How the effectiveness is after the vacancies were reduced? The data in Table 2 shows that the values of λ increase with temperature increasing. The λ of sample A6 achieved the maximum value at 1293 K. This result proves that the magnetostriction is related with the atomic vacancies of $Tb_{0.3}Dy_{0.7}Fe_{1.95}$ alloy. Reducing the concentration of vacancy is favorable for enhancing magnetostrictive property of the alloy.

The λ value of sample A6 is so high (1211 ppm) under lower magnetic field (40 kA/m) as shown in Table 2. High magnetostrictive performance is attributed to the integral crystal structure. As we know, the liner magnetostriction originates from the movement of non-180° domain walls and the rotation of magnetic moments. Any defect in the crystalline structure will hinder the magnetizing procedure. The atomic vacancy is the same. The vacancy structure causes crystal lattice distortion. Lattice distortion sets off a movement of atoms around the vacancies and it propagates a long distance. This distortion of crystal lattice brings about an increase of internal stress and causes an increase of applied magnetic field. As a result, the vacancies lead to variations of magnetostriction under the same external magnetic fields.

4. Conclusions

(1) The average value of positron lifetime of $Tb_{0.3}Dy_{0.7}Fe_{1.95}$ samples with different heat treatment is different, and it reflects that the heat treatment can change the concentration of vacancy defect in a sample.
(2) The atomic vacancy can be removed from the internal to surface of alloy by diffusion process. The removal effectiveness of vacancies depends on the annealing temperature.
(3) Magnetostriction is related to the atomic vacancies of $Tb_{0.3}Dy_{0.7}Fe_{1.95}$ alloy. Reducing the concentration of vacancy is favorable to enhance magnetostrictive property of the alloy.

References

[1] J.D. Verhoeven, E.D. Gibson, O.D. McMasters, H.H. Baker, Metall. Trans. 18 (1987) 223.
[2] A.E. Clark, J.D. Verhoeven, O.D. McMasters, E.D. Gibson, IEEE Trans. Magn. 22 (5) (1986) 973.
[3] M.C. Zhang, X.X. Gao, S.Z. Zhou, Z.H. Shi, J. Alloys Compd. 318 (2004) 226–228.
[4] W. Wei, H.J. Tang, M.C. Zhang, X.X. Gao, J.P. He, S.Z. Zhou, J. Alloys Compd. 413 (2006) 96–100.
[5] H.J. Tang, M.C. Zhang, X.X. Gao, S.Z. Zhou, J. Chin. Rare Earth Soc. 23 (1) (2005) 44–47 (in Chinese).