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ScienceDirect
Journal of Magnetism and Magnetic Materials 311 (2007) 702–707
www.elsevier.com/locate/jmmm

A comparative study of the magnetoelastic properties of the $YFe_{10}V_2$ and $NdFe_{10}V_2$ compounds

M.R. Alinejad[a,*], N. Tajabor[a], H. Khandan Fadafan[a], D. Fruchart[b,c], D. Gignoux[d]

[a]*Department of Physics, Ferdowsi University of Mashhad, Mashhad 91775-1436, Iran*
[b]*Laboratoire de Cristallographie, CNRS, BP 166, 38042 Grenoble Cedex 9, France*
[c]*CRETA, CNRS, BP 166, 38042 Grenoble Cedex 9, France*
[d]*Laboratoire Louis Néel, BP 166, 38042 CNRS, Grenoble Cedex 9, France*

Received 24 April 2006; received in revised form 21 August 2006
Available online 26 September 2006

Abstract

The magnetoelastic properties of iron-rich $REFe_{10}V_2$ (RE = Nd, Y) compounds were studied via magnetostriction and thermal expansion measurements in the 5–300 K range of temperature in up to 6 T external fields. Results of thermal expansion analysis show that the spontaneous magnetostriction of the compounds mostly originates from itinerant magnetization. Besides, the small volume striction appearing in the thermal expansion of the Nd compound close to 50 K suggests the existence of a basal to conical spin re-orientation transition. The volume magnetostriction isotherms of both compounds take minimum values for external field corresponding to the anisotropy field. In addition, the anisotropic and the volume magnetostriction traces of the $NdFe_{10}V_2$ take marked maxima under low field, with a relatively large initial magnetostrictivity, again more pronounced at the conical–axial spin re-orientation transition ($T_{SR} = 130$ K). Analysis of the anisotropic magnetostriction of the Nd compound leads to the conclusion that the contribution of Nd–Fe interactions is negligible. The temperature dependence of volume magnetostriction is in good agreement with prediction of a phenomenological model based upon a fluctuating local band theory. This analysis shows that the difference between the forced volume strictions of Y and Nd compounds below and above T_{SR} originates from the Nd sublattice magnetization.

Keywords: Ferromagnetism; Thermal expansion; Magnetostriction; Magnetoelastic; Magneto-crystalline anisotropy

1. Introduction

Iron-rich $REFe_{12-x}M_x$ (1–12) alloys (where RE is a rare earth element, and M is V, Ti, Mo, etc…) have received great attention during past years as good candidates for hard permanent magnet applications. This comes from rather high Curie temperatures, excellent magnetic properties and a simple crystal structure [1,2]. The latter characteristic makes the series particularly appropriate for basic researches. The structure is tetragonal $ThMn_{12}$ type, SG I4/mmm, with three nonequivalent sites (8*i*, 8*j* and 8*f*) for Fe and M together and one site (2a) for rare earth. Compounds with nonmagnetic or light RE elements are ferromagnets and those with heavy RE elements are ferrimagnets. It was found that $Nd(Fe,V)_{12}$ compounds exhibit optimized intrinsic magnetic properties in the series [3–5]. In these (1–12)-type compounds, the Fe sublattice has uniaxial magnetic anisotropy, while that of the RE sublattice is planar. Competition of these two anisotropies potentially result in spin re-orientation transition T_{SR} from planar to axial and from low to high temperatures. For $NdFe_{10}V_2$, a spin re-orientation was found at $T_{SR}\sim130$ K [5].

Compared with other RE–Fe systems, only a few investigations on the magnetoelastic properties of the (1–12) series are reported to date [6–8]. Considering the nonmagnetic Y element, we have comparatively studied the magnetostriction and the thermal expansion of $REFe_{10}V_2$ with RE = Y, Nd, in order to question the contribution of local (4f) and itinerant (3d) magnetism on the magnetoelastic properties. This study is relevant for practical applications' as well as to better understand the basic magnetic behavior of Fe and Nd in 1–12 compounds.

*Corresponding author. Tel.: +98 511 879 3912; fax: +98 511 879 6416.
E-mail address: alinejad@ferdowsi.u.ac.ir (M.R. Alinejad).

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doi:10.1016/j.jmmm.2006.08.035

2. Experimental methods

Vanadium-containing compounds $Nd(Y)Fe_{10}V_2$ have been synthesized by arc melting of the constituent elements (grade purity 3 N) in a water-cold copper boat under high purified argon atmosphere. As-cast ingots were annealed in 10^{-4} mb evacuated chamber of a specific furnace. Annealing has been executed at $T = 960\,^{\circ}C$ for 24 h. The crystalline state of the compounds were assessed from X-ray diffraction (XRD) patterns on powdered samples. The patterns were recorded at room temperature (RT) using a computer controlled diffractometer with $Fe(K_\alpha)$ radiation and 0.05° step angle. The lattice parameter refinements have been done using the CELREF software. To check the orientation of the easy magnetization direction at RT, XRD analyses were performed on samples previously aligned in a field of 0.7 T parallel to the scattering vector.

For magnetization measurements, aligned cylindrical samples with 5 mm diameter were prepared by embedding the powders with epoxy resin and exposing until the epoxy hardened to a 0.7 T field parallel to the cylinder axis. Perpendicular alignments with respect to the cylinder axis were realized using a rotating device. Parallel magnetization measurements were performed at temperatures that comprised between 5 and 300 K and in magnetic fields up to 10 T, using an extraction-type magnetometer. The saturation magnetization was derived from the high-field extrapolation of M against $1/H^2$ curves to $1/H^2 = 0$. The anisotropy field H_a was deduced using the singular point detection (SPD) method. Temperature dependence of low-field magnetic susceptibility ($\chi(T)$) was measured using a high-sensitivity thermomagnetic torque. All our results of the magnetization of the samples were found as fairly consistent with the literature [3–5].

Magnetostriction and thermal expansion measurements were performed in the range 5–300 K and in up to 5 T external fields using semi-spherically shaped samples with ~6 mm diameter. For these measurements, a commercial capacitance dilatometer system was used. Magnetostriction was measured parallel (λ_t) and perpendicular (λ_n) to the field direction, from which the anisotropic magnetostriction, $\Delta\lambda = \lambda_t - \lambda_n$, and the volume magnetostriction, $\Delta v/v = \lambda_t + 2\lambda_n$, were deduced.

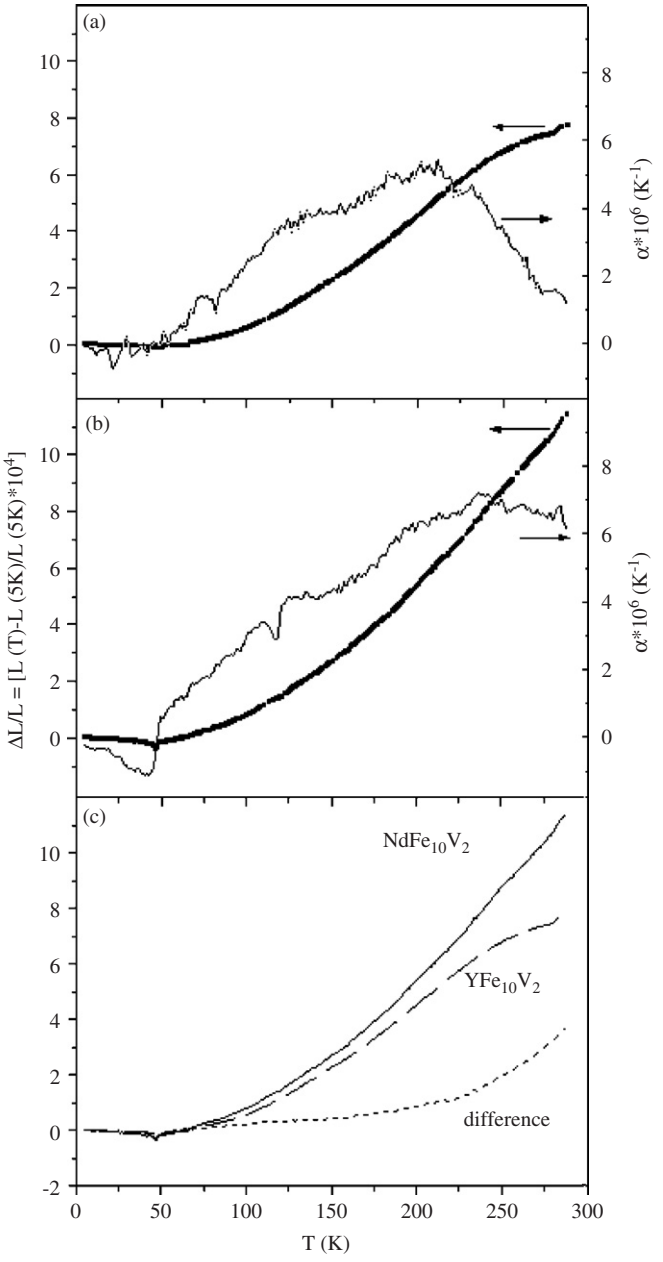

Fig. 1. Thermal expansion of (a) $YFe_{10}V_2$, and (b) $NdFe_{10}V_2$ and corresponding coefficients $\alpha \equiv (d/dT)(\Delta L/L)$. (c) Difference of the thermal expansion between the two studied compounds.

3. Results

X-ray diffraction patterns of the samples show that the samples are single 1–12 phase. Analysis of the patterns leads to the tetragonal lattice parameters $a = 8.56$ Å and $c = 4.77$ Å for $NdFe_{10}V_2$ alloy, and $a = 8.49$ Å and $c = 4.77$ Å for $YFe_{10}V_2$ alloy, in good agreement with the literature [1].

Fig. 1 shows the thermal expansion of both samples, as well as the differential expansion. The results are consistent with literature related to other 1–12 compounds, comprising magnetic and nonmagnetic RE, respectively [1,7]. In fact, the thermal expansion of both compounds should follow a T^4—Grüneisen-type behavior at low temperature and then it should exhibit an Invar-type behavior above RT. Although this is satisfied for the Y compound as shown in Fig. 1a, between 40 and 80 K the thermal expansion coefficient of the Nd compound does not fulfill the expected behavior [3], as shown in Fig. 1b. The most anomalous aspects of the results are first the small but negative thermal expansion coefficient of the $NdFe_{10}V_2$ compound as measured below 40 K and then a spin re-orientation type of transition occurring at ~50 K. Contrarily, the well-known spin re-orientation transition exhibited by $NdFe_{10}V_2$, from basal plan to c-axis and