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Spin reorientation phenomena in the $NdYFe_{14-x}Co_xB$ system

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Abstract

Two types of spin reorientation transitions in $NdYFe_{14-x}Co_xB$ ($0 < x < 14$) were evidenced with the use of an AC susceptometer and a Faraday magnetic balance. The transitions are of 'cone to axis' type (below 125 K) in the whole composition range, and of 'axis to plane' type (above 325 K) for $x > 8$. The phase diagram is compared with Nd- and Y-based systems. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Spin reorientation; Intermetallic compounds; Anisotropy

The magnetic properties of $R_2T_{14}B$ (R = rare earth, T = Fe or Co) originate from a complex interplay between crystalline electric field and exchange interaction. The high magnetocrystalline anisotropy of the R- and 3d metal sublattices as well as their different variations with temperature are the reasons for the two types of spin reorientation transitions (SRT) observed in compounds with R = Nd, Ho, Er, Tm, and Yb (for the Fe-based compounds) and with R = Pr, Nd, and Tb (for Co-based compounds): a cone (or planar)-to-axis transition (SR1) at low temperature and an axis-to-plane transition (SR2) at higher temperature. The behaviour of both sublattices is coupled through exchange interactions. The properties of the R- and 3d-sublattice anisotropies have been studied by numerous substitutions done separately either in the R or in the 3d-sublattices [1–3]. Keeping in mind that Co and Fe display different anisotropic behaviour and also a tendency to preferential occupation in 2 : 14 : 1 systems [2–6], we made an attempt to combine the influence of substituents in both sublattices in order to gain some information on the resulting anisotropy of such multicomponent system, as it is not the simple algebraic sum of the individual R- and 3d-sublattice contributions.

Polycrystalline materials of compositions $NdYFe_{14-x}Co_xB$ (x = 14, 13, 12, 11, 10, 9 and $Nd_2Co_{14}B$) were alloyed by means of induction heating in a purified argon protective atmosphere. As-cast ingots were wrapped in tantalum foil, sealed into quartz tubes filled with argon and annealed at 900°C for two weeks. X-ray and thermomagnetic analysis were used to verify that the materials were single phase and to establish their Curie temperatures, T_c. Oriented powder samples, embedded in epoxy in a field of 1 T, were studied by X-ray at 295 K in order to confirm their axial bulk anisotropy.

Low temperature measurements were performed on an AC susceptometer. Typical peaks in χ' were observed, which were attributed to SRTs of the 'cone to axis' type as temperature increases. The corresponding transition temperature, T_{SR1}, was determined at the inflection point after the peak. Above room temperature, a Faraday-type magnetic balance was used to observe features in the temperature dependence of the magnetisation, which can indicate SRTs. The measurements were performed heating and cooling at rates between 2°C and 5°C/min. As shown in Fig. 1, the signals measured by the balance increase with temperature and, after a plateau, they drop in the paramagnetic phase. The cooling curves show similar features, with a higher remaining value at room temperature. Following the classification of SRTs for polycrystalline materials [7], the anomalies observed in the Faraday balance curves indicate spin reorientations of 'axis to plane' type with increasing temperature. They

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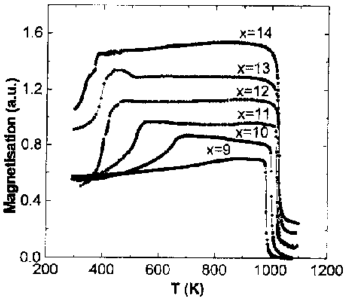

Fig. 1. Faraday balance curves for $NdYFe_{14-x}Co_xB$ above room temperature (heating cycle). Each curve has been rescaled for comparison purposes.

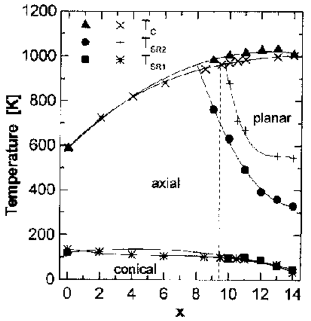

Fig. 2. Diagram of spin configuration types observed in $NdYFe_{14-x}Co_xB$ (this work, full symbols), in $Nd_2Fe_{14-x}Co_xB$ ([8], other symbols) and in $Y_2Fe_{14-x}Co_xB$ (dashed line separating axial and planar phases).

were observed only for Co-rich compounds, namely for $x > 8$. The spin reorientation temperatures, T_{SR2}, were taken as coinciding with inflection points (estimated experimental error ± 5 K).

Fig. 2 shows the spin phase diagram for the system studied. It is combined for comparison with those of $Nd_2Fe_{14-x}Co_xB$ [8] and $Y_2Fe_{14-x}Co_xB$ [9]. The spin phase diagram of $Y_2Fe_{14-x}Co_xB$ is composed of two regions: compounds with Co concentration $x < 9$ show axial spin arrangement, while those with $x > 10$ are planar, displaying the competition between the axial and planar anisotropies of Fe and Co, respectively. There is no SR1 transition induced by changing the temperature, which indicates that SR1 is produced by the R-sublattice anisotropy. In contrast, $Nd_2Fe_{14-x}Co_xB$ [8] shows SR1 transitions throughout the full composition range and SR2 transitions for $x > 9$. T_{SR1} is little dependent on the Co concentration (SRT temperatures varing in a temperature interval $\Delta T_{SR1} < 35$ K) up to $x \approx 10$, approximately the concentration from which the Co planar anisotropy overcomes the Fe axial anisotropy at higher temperatures and produces a SR2 transition. This has been interpreted as an exchange effect produced through a decrease of the average 3d magnetic moment as Co is incorporated. Slight concentration dependences of T_{SR1} have also been found in $Nd_{2-y}Y_yFe_{14}B$ up to $y = 1.8$ ($\Delta T_{SR1} < 20$ K) and $Nd_{2-y}Y_yCo_{14}B$ ($\Delta T_{SR1} < 40$ K for $y < 1.8$) [10]. All that information provides a description of SR1 transitions as due to the temperature dependence of the magnetocrystalline anisotropy of isolated R atoms with a weak influence of the 3d-sublattice. Our results of $NdYFe_{14-x}Co_xB$ corroborate this description, since T_{SR1} is almost identical to those in $Nd_2Fe_{14-x}Co_xB$.

Unlike SR1, SR2 is governed by both the 3d and R sublattices anisotropies, as shown in the competition of Fe and Co anisotropies in $Nd_2Fe_{14-x}Co_xB$ and the necessity of a rare earth with magnetic moment, but it additionally displays the influence of the exchange interactions. Our results on $NdYFe_{14-x}Co_xB$ show this through two differences with respect to the $Nd_2Fe_{14-x}Co_xB$ phase diagram: (i) T_{SR2} decreases with increasing Co concentration. The introduction of Y into the Nd sublattice reduces the average exchange interaction, which is proportional to the magnetisation of the sublattices, while the overall anisotropy of the Nd-sublattice does not change appreciably as explained above. The change in the exchange interaction is such that the 3d-sublattice anisotropy and its planar tendency (in the Co-rich range of composition) dominate over a wider temperature range than in the $Nd_2Fe_{14-x}Co_xB$ system: 460 K in $Nd_2Co_{14}Ca_xB$ and 700 K in $NdYCo_{14}B$. (ii) The threshold composition for observing a planar phase in the $NdYFe_{14-x}Co_xB$ system is $x \approx 8$, while for the $Nd_2Fe_{14-x}Co_xB$ and $Y_2Fe_{14-x}Co_xB$ systems is $x > 9$. This is a surprising result, since the data of the Nd and Y systems point to a lower limit concentration of $x > 9$ for the appearance of the Co induced planar phases.

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