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DOI
10.1016/0304-8853(94)01243-1

Publication date
1995

Published in
Journal of Magnetism and Magnetic Materials

ELSEVIER

Journal of Magnetism and Magnetic Materials 140–144 (1995) 1025–1026

journal of magnetism and magnetic materials

Magnetocrystalline anisotropy of $SmFe_{12-x}Mo_x$ compounds with $x = 0.5$, 1.0, 1.5, 2.0 or 3.0

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Abstract

The magnetic anisotropy fields of $SmFe_{12-x}Mo_x$ compounds with $x = 0.5$, 1.0, 1.5, 2.0 or 3.0 were determined up to the Curie temperature using the SPD technique. An anomalous increase in the magnetization was detected at 4.2 K in the compounds with $x = 1.0$, 1.5 or 2.0 by measuring the magnetization on magnetically aligned samples with external fields applied parallel or perpendicular to the alignment direction.

$SmFe_{10}Mo_2$ crystallizes in a tetragonal structure related to $ThMn_{12}$ in which there are three crystallographic non-equivalent Fe and/or Mo sites, namely 8f, 8i, and 8j, and only one Sm site. Mo atoms preferentially occupy only 8i sites [1]. It was reported that the tetragonal structure can be stabilized in $YFe_{12-x}Mo_x$ with $x = 0.5$ [2]. The Curie temperature and the magnetization are enhanced in the compounds with lower Mo contents. From the applications point of view, $SmFe_{12-x}Mo_x$ alloys are interesting due to their high magnetic anisotropy which is of vital importance for possible permanent magnets.

Ingots of $SmFe_{12-x}Mo_x$ with nominal composition $x = 0.5$, 1.0, 1.5, 2.0, 3.0 and 4.0 were prepared by induction melting appropriate amounts of raw materials of purity better than 99.99 wt%. The purity of the samples was checked by X-ray diffraction. It was found that all investigated samples consist of the main phase with the tetragonal structure related to $ThMn_{12}$ and α-Fe as impurity phase, except for $SmFe_{10}Mo_2$, in which only the tetragonal phase was detected, and $SmFe_8Mo_4$, in which the matrix phase is not the tetragonal phase.

Using the singular point detection (SPD) technique, the value of anisotropy field, B_a, can be determined directly from a peak in the curve of d^2M/dB^2 versus B [3]. It is worthwhile to note that the position of this peak depends only on the magnetocrystalline anisotropy of the hard magnetic phase included in the sample. The impurity phases do not contribute. Fig. 1 shows the temperature dependence of B_a in $SmFe_{12-x}Mo_x$ compounds with $x = 0.5$, 1.0, 1.5, 2.0 and 3.0. It is evident that upon reduction of the Mo content the anisotropy of $SmFe_{12-x}Mo_x$ is enhanced. In $SmFe_{12-x}Mo_x$ compounds, the contribution to the net magnetocrystalline anisotropy is dominated by the Sm sublattice anisotropy, which originates from the crystalline electric field (CEF) and the exchange field experienced by the Sm^{3+} ion. As mentioned above, the Mo atoms occupy only 8i sites, which are the nearest Fe and/or Mo sites to the Sm^{3+} ion. Variation of the Mo concentration will result in a remarkable change in the crystal field acting on the Sm^{3+} ion and therefore in the net magnetic anisotropy field.

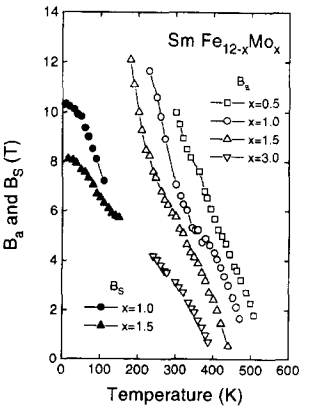

Fig. 1. Temperature dependence of the anisotropy field B_a and of the field B_s where magnetization changes most rapidly when a field is applied perpendicular to the alignment direction in $SmFe_{12-x}Mo_x$ compounds with $x = 0.5$, 1.0, 1.5, 2.0 and 3.0.

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SSDI 0304-8853(94)01243-1

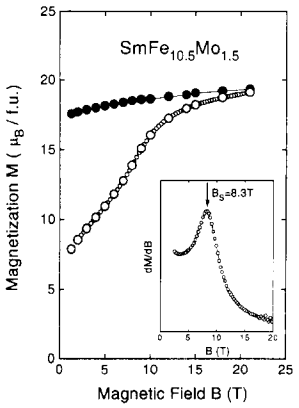

Fig. 2. Magnetization at 4.2 K measured on magnetically aligned $SmFe_{10.5}Mo_{1.5}$ with field applied parallel (●) or perpendicular (○) to the alignment direction. The large and small dots represent the measurements obtained employing 'stepwise' and 'continuous' field pulses. The inset shows dM/dB versus B for determining B_s.

The magnetization of $SmFe_{12-x}Mo_x$ compounds with $x = 1.0$, 1.5 and 2.0 was measured at 4.2 K on magnetically aligned samples with external magnetic fields applied parallel or perpendicular to the alignment direction. Fig. 2 shows the results measured for $SmFe_{10.5}Mo_{1.5}$. The values of the spontaneous magnetization M_s were obtained by extrapolating the high-field (> 8 T) magnetization, measured with the field applied parallel to the alignment direction, to zero field, and are listed in Table 1. It is obvious that the value of M_s remains unchanged upon variation of the Mo concentration. In addition, an anomalous increase in the magnetization is found when a field is applied perpendicular to the alignment direction. The field B_s at which the magnetization increases most rapidly can be easily determined by the maximum appearing in the first derivative of M, as shown in the inset of Fig. 2. From the SPD measurements, it follows that this anomaly is detectable only below 110, 150 or 170 K for $SmFe_{12-x}Mo_x$, with $x = 1.0$, 1.5 or 2.0, respectively.

Table 1
Curie temperature T_C, magnetocrystalline anisotropy field, B_a, field, B_s, at which the magnetization increases most rapidly, and spontaneous magnetization M_s of $SmFe_{12-x}Mo_x$

Compounds	T_C (K)	B_a (T) (300 K)	B_s (T) (4.2 K)	M_s (μ_B/f.u.) (4.2 K)
$SmFe_{11.5}Mo_{0.5}$	544	10.0	–	–
$SmFe_{11}Mo$	509	7.1	10.4	18.0
$SmFe_{10.5}Mo_{1.5}$	456	5.8	8.4	18.0
$SmFe_{10}Mo_2$	430	4.8	7.2	18.4
$SmFe_9Mo_3$	–	3.12	–	–

In the R–T compounds, the anomalous increase in magnetization with respect to the applied field is usually cited as a first-order magnetization process (FOMP), which is characterized by a discontinuous jump in the magnetization curve when the field is applied parallel to a specific crystallographic direction. The physical origin of a FOMP is due to the appearance of two relative minima in the total magnetic energy as a function of the angle between the magnetization and the c-axis. In a CEF calculation for $SmFe_{11}Ti$ [4], only one minimum was found. However, this minimum shifts rapidly in the field range where the anomalous increase in magnetization is detected. The anomalous increase in the magnetization detected there was therefore suggested to be due not to a FOMP, but rather to a rapid, continuous rotation of magnetic moments under the action of the external field. Since this anomalous increase in magnetization is caused by the Sm sublattice anisotropy, which is similar for all Sm-containing $ThMn_{12}$-type compounds, we suggest that the physical origin of the anomalous increase in magnetization found for $SmFe_{12-x}Mo_x$ compounds is also not due to a FOMP.

Acknowledgements: This work was supported by the Fonds zur Förderung der Wissenschaftlichen Forschung of Austria under project Nos. S5604 and S5605. The high-field measurements at the Amsterdam High Field Installation were carried out within the scientific exchange programme between China and the Netherlands. E.H.C.P. Sinnecker thanks the ÖAD for financial support.

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