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MOESSBAUER AND MAGNETIC MEASUREMENTS OF RARE EARTH-IRON-TRANSITION METAL COMPOUNDS WITH $ThMn_{12}$ TYPE STRUCTURE

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Abstract. – The magnetic properties of ternary alloys with general formula $RFe_{12-x}T_x$ (R = Gd, Sm, Y, Nd, T = Mo, Ti, V) have been studied by magnetization and Moessbauer measurements. Curie temperatures are in the range of 350 to 600 K and anisotropy fields are comparable to $R_2Fe_{14}B$ type compounds. A spin reorientation transition has been observed in $NdFe_{9.8}V_{2.2}$.

Introduction

Following the establishment of the ternary rare earth-iron-boron compounds with the $R_2Fe_{14}B$ structure as outstanding permanent magnet materials, the search for other rare earth-iron alloys with similar properties was actively pursued in the last two years. The most fruitful area for this effort has been the class of ternary compounds with general formula $RFe_{12-x}T_x$, crystallizing in the $ThMn_{12}$ type structure with $1 \leq x < 2$ and T a transition metal or metalloid element. Preparation of this type of compounds has been reported for the whole lanthanide series from Nd to Lu, T = V and $x = 2$ [1] as well as for various rare earth elements and T = Ti, V, Cr, Mo and Si [2] with $x \geq 1$. The stabilization of $GdFe_xAl_{12-x}$ alloys for $x = 6, 8, 10$ by melt spinning has also been reported [3].

The magnetic structure of these compounds at low temperatures is dominated by the anisotropy of the rare earth ion. Anisotropy fields are comparable to the $R_2Fe_{14}B$ compounds and vary with the type of the rare earth atom. A value of 15 T has been reported for $SmFe_{10}V_2$ while for $YFe_{10}V_2$ the anisotropy field is 4 T [1]. The latter result indicates that a substantial part of the anisotropy is carried by the iron sublattice. Curie temperatures range between 350 and 610 K and iron sublattice magnetizations are somewhat lower than in $R_2Fe_{14}B$ alloys.

We report in this paper the results of magnetic and Moessbauer studies on a series of alloys with compositions (R = Gd, Y, Sm; T = Mo; $1.8 \leq x \leq 2.2$) (R = Gd, Y, Sm; T = Ti; $x = 1$) and (R = Nd; T = V; $x = 2.2$). The Moessbauer measurements are expected to provide information on the site distribution of the T atom in the three different iron sites of the $ThMn_{12}$ structure and the magnetic moments of iron atoms in these sites.

Results and discussion

The studied alloys were prepared by arc melting the constituents and annealing at 900 °C in an argon atmosphere for 10 days. The purity for the starting materials was 3 *N* for the rare earths and 4 *N* for the remaining constituents. A small excess (10 %) of the rare earth constituent in the composition of the melt was found useful for the preparation of single phase samples.

The presence of the tetragonal $ThMn_{12}$ type phase was ascertained by X-ray powder diffraction diagrams using Co-Ka radiation. Within the resolution of these measurements no other phase was detected except in the case of the Sm compounds where a small iron admixture was present.

The temperature dependence of the magnetization was measured in the range of 4.2 to 700 K in an applied field of 50 mT. Curie temperatures determined from these graphs are listed in table I. Approximate values for the saturation magnetization at 4.2 K and the anisotropy field were obtained by measurements on samples of oriented powders set in epoxy under the influence of a magnetic field of 1.8 T. The estimated values of the saturation magnetization and the anisotropy field are included in table I.

Table I. – *Magnetic Properties of* $RFe_{12-x}T_x$ *alloys: Curie temperature, Saturation Magnetization at* 4.2 K, *Anisotropy Field at* 300 K *and Average Hyperfine Field at* 80 K.

Alloy	T_c (K)	M_s (μ_B/f.u.)	H_A (T) 300 K	B_{hf} (T) 80 K
$Gd_{1.1}Fe_{9.8}Mo_{2.2}$	370	8.0	–	–
$Gd_{1.1}Fe_{10}Mo_2$	440	8.3	2.8	22.0
$Gd_{1.1}Fe_{10.2}Mo_{1.8}$	484	9.9	–	–
$Y_{1.1}Fe_{10}Mo_2$	360	13.5	2.1	19.8
$Sm_{1.2}Fe_{10}Mo_2$	460	15.0	> 5.0	–
$GdFe_{11}Ti$	600	13.2	3.5	29.3
$YFe_{11}Ti$	520	19.0	3.0	28.0
$Nd_{1.2}Fe_{9.8}V_{2.2}$	570	17.2	–	–

The Curie temperatures in table I are in agreement with recently reported values in similar compounds [2]. The Mo alloys show lower T_c values than the Ti alloys, at least partly due to the fact that the range of stabilization for the former is around $x = 2$. The results of the Gd-Mo samples indicate that the homogeneity range extends to the values $1.8 \leq x \leq 2.2$. The iron sublattice magnetization as obtained from the Y alloys is 1.35 μ_B and 1.73 μ_B per iron atom for T = Mo and Ti respectively which may be compared with a value of 2.2 μ_B for $YFe_{14}B$ [4]. The anisotropy field of $YFe_{11}Ti$ is approximately 3 T, while the anisotropy field of $YFe_{14}B$ is reported as about 1.5 T [5]. The iron sublattice anisotropy, therefore, appears to be stronger in the $RFe_{12-x}T_x$ compounds.

In view of the above result the magnetization in the Nd alloy is expected to show a reorientation from a direction perpendicular to the c axis at low temperature, where the negative Steven's factor for Nd favors this orientation, to a direction parallel to the c axis. The variation of magnetization as a function of temperature in a field of 50 mT is shown in figure 1. An abrupt change in magnetization is observed near 120 K both with rising and falling temperature. The occurrence of spin reorientation has been confirmed by Moessbauer measurements on an oriented absorber at room temperature and 80 K. A detailed study of the transition by Moessbauer and magnetization measurements is in progress. Spin reorientation has been reported also recently in $DyFe_{11}Ti$ and has been analysed by a crystal field model [6]. In this compound the shift of the magnetization from the plane to the c axis is found to occur gradually in the range of 100 to 200 K.

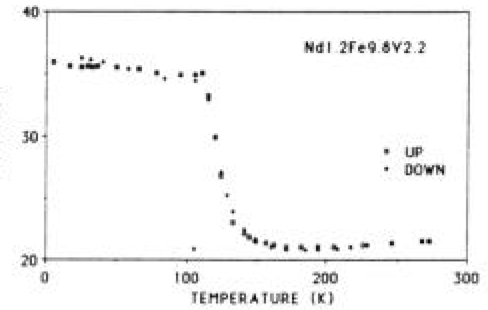

Fig. 1. – Temperature dependence of the magnetization of the $Nd_{1.2}Fe_{9.8}V_{2.2}$ alloy.

The Moessbauer spectra show incompletely resolved magnetic hyperfine patterns arising from iron atoms in the 4i, 4j and 4f positions of the $ThMn_{12}$ type lattice. A typical spectrum of $YFe_{11}Ti$ at 80 K is shown in figure 2. An initial fit of these data was obtained with three magnetic hyperfine components taking into account the broadening of the lines due to the distribution of the number of Ti neighbors in each site. In accordance with neutron diffraction data [7], we have assumed that Ti enters preferentially in the i site. The average hyperfine field is 27.8 T. From this value we

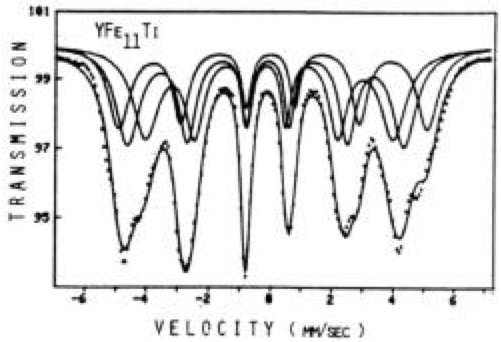

Fig. 2. – Moessbauer spectrum of $YFe_{11}Ti$ at 80 K.

calculate an average iron moment of 1.88 μ_B using a conversion factor of 14.8 T/μ_B. This value may be compared with 1.73 μ_B obtained from the magnetization results (Tab. I). The difference is probably due to incomplete saturation in the magnetization data. Average hyperfine fields have been obtained also by the same procedure for the other alloys and the results are included in table I.

In conclusion, the foregoing data for the $RFe_{12-x}T_x$ alloys show that they exhibit Curie temperatures and anisotropy fields sufficiently high to be of interest as permanent magnet materials. The iron sublattice magnetization as estimated from magnetization and Moessbauer spectra is somewhat lower than in $R_2Fe_{14}B$ type materials.

Acknowledgments

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[1] De Boer, F. R., Huang, Y. K., de Mooij, D. B. and Buschow, K. H. J., *J. Less-Common. Met.* **135** (12987) 199.

[2] Buschow, K. H. J., de Mooij, D. B., Brouha, M., Smit, H. H. A. and Thiel, R. C., *IEEE Trans. Magn.* (April 1988).

[3] Wang Xian-Zhong, Chevalier, B., Berlurean, T., Etourneau, J., Coey, J. M. D. and Cadogan, J. M., *J. Less-Common. Met.* **138** (1988) 235.

[4] Bolzoni, F., Gavigan, J. P., Givord, D., Li, H. S., Mose, O. and Pareti, L., *J. Magn. Magn. Mater.* **66** (1987) 158.

[5] K. H. J. Buschow, *Mater. Sci. Rept.* **1** (1986) 1.

[6] Li Hong-Shuo, Hu Bo-Ping and Coey, J. M. D., *Solid State Commun.* **66** (1988) 133.

[7] Mose, O., Pareti, L., Zolsi, M. and David. W. I. F., *Solid State Commun.* **66** (1988) 465.