FORCED VOLUME MAGNETOSTRICTION IN RAPIDLY QUENCHED AMORPHOUS R-Fe (R = Pr, Nd, Gd, Dy AND Y) ALLOYS

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Abstract. – The forced volume magnetostriction $(\partial\omega/\partial H)$ of $R_{1-x}Fe_x$ (R = Pr, Nd, Gd, Dy and Y: $0.4 < x < 0.9$) alloys has been measured at temperatures from 77 K to 400 K. The contribution from the molecular field of Fe and R subnetworks to $(\partial\omega/\partial H)$ is discussed.

1. Introduction

Rare earth metal(R)-transition metal(TM) compounds exhibit a large magnetovolume effect. While the magnetovolume effect of RCo_2 originates from the strong molecular field of the rare earth [1], that of RMn_2 may be attributed to the dependence of Mn magnetic moments on the volume [2]. On the other hand, in amorphous Fe-TM and Fe-metalloid alloys, dense-packed Fe atoms in the amorphous states cause the instability of ferromagnetism and the large magnetovolume effect [3]. Although it is known that amorphous R-Fe alloys show a magnetovolume effect, only a few experimental works were carried out so far. Present paper describes the experimental results of the forced volume magnetostriction in amorphous R-Fe alloys.

2. Experimental

Amorphous $R_{1-x}Fe_x$ alloys were prepared by a rapid quenching in an argon atmosphere. They were formed into ribbon, about 1 mm and 10-20 μm thick, and the amorphous structure was confirmed by X-ray Debye-Scherrer analysis. The magnetostriction was measured by a three terminal capacitance method in magnetic fields up to 20 kOe and in temperatures from 77 K to 400 K [3]. The forced volume magnetostriction $(\partial\omega/\partial H)$ is defined by $(\partial\omega/\partial H) = \partial\left(\lambda_{\parallel} + 2\lambda_{\perp}\right)/\partial H$, where $\lambda_{\parallel} + 2\lambda_{\perp}$ is volume expansion due to applied fields. In this investigation, the value of $(\partial\omega/\partial H)$ was evaluated by using data between 10 kOe and 20 kOe.

3. Experimental results

Figure 1 shows the temperature dependence of $(\partial\omega/\partial H)$ for $Nd_{1-x}Fe_x$. Curie temperatures indicated by arrows were determined by Arrott plots. The $(\partial\omega/\partial H)$ value for $x = 0.8$ is about 55×10^{-10} Oe^{-1} at 77 K and increases to about 295×10^{-10} Oe^{-1} at T_c. Hysteretic λ-H curves were observed at low temperatures for $x \leq 0.7$ and, below T_{Hc}, λ-H curves became irreversible even at more than 10 kOe. In this case, $(\partial\omega/\partial H)$ was evaluated by using λ-H curves in decreasing H and this causes the sudden decrease of $(\partial\omega/\partial H)$ as can be seen in the figure. This phenomenon relates to an extraordinary coercive force found at low temperatures for Pr, Nd, Dy-Fe alloys [4].

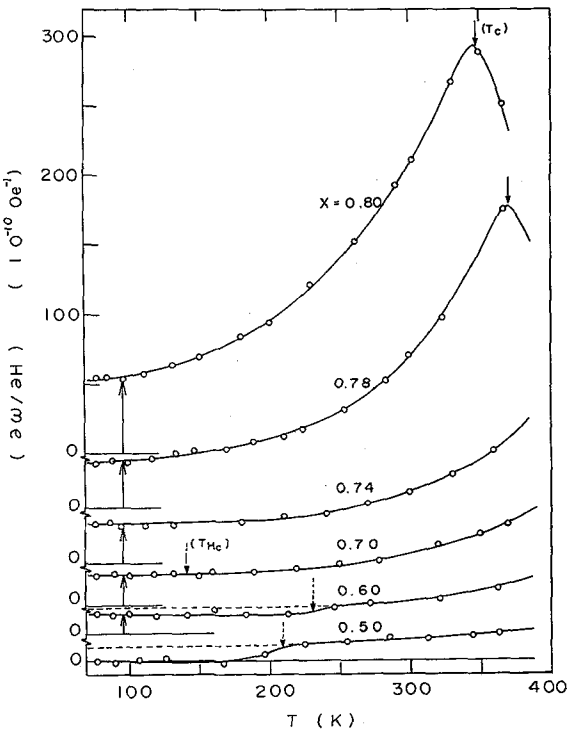

Fig. 1. – Temperature dependence of $(\partial\omega/\partial H)$ for amorphous $Nd_{1-x}Fe_x$ alloys.

The temperature dependence of $(\partial\omega/\partial H)$ for Gd-Fe is shown in figure 2. While $(\partial\omega/\partial H)$ for $x = 0.7$ is negative in temperatures from 77 K to 400 K, $(\partial\omega/\partial H)$ for $x = 0.6$ changes a sign at about 220 K.

The composition dependence of $(\partial\omega/\partial H)$ at 77 K is shown in figure 3. The data points having error bars were obtained by an extrapolation from temperatures above T_{Hc}. The $(\partial\omega/\partial H)$ values for the amorphous R-Fe alloys decrease rapidly with decreasing x, which is the same trend as the result for Fe-B [3]. It should be noted here that the sign of $(\partial\omega/\partial H)$ for R = Gd and Dy changes from positive to negative around $x = 0.8$ with decreasing x. Magnetization

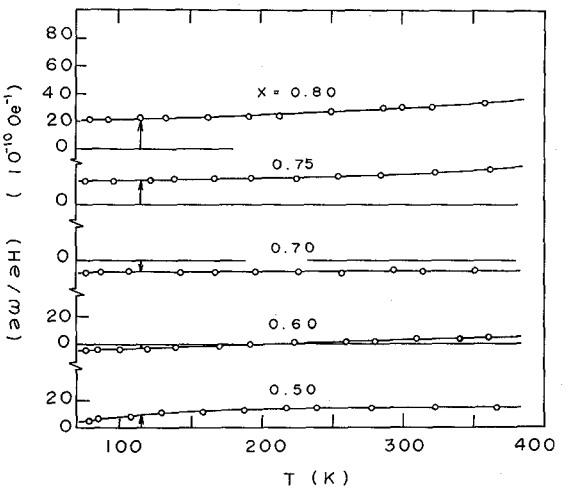

Fig. 2. – Temperature dependence of $(\partial\omega/\partial H)$ for amorphous $Gd_{1-x}Fe_x$ alloys.

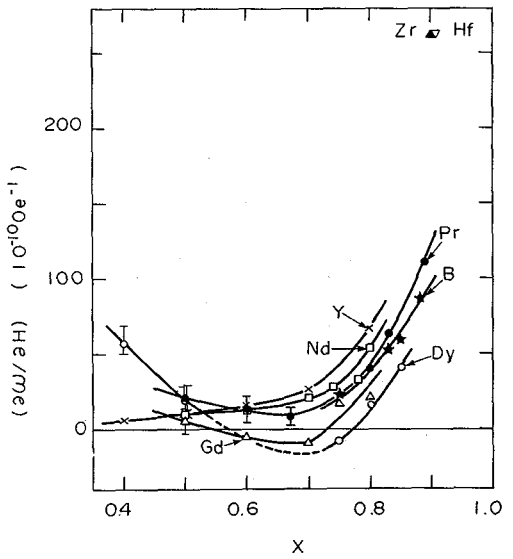

Fig. 3. – Composition dependence of $(\partial\omega/\partial H)$ at 77 K for amorphous $R_{1-x}Fe_x$ alloys. The results of Fe-B, Zr, Hf alloys are also shown.

measurements revealed that a magnetic compensation composition x_{comp} at 77 K is 0.78 for $Dy_{1-x}Fe_x$ and 0.75 for $Gd_{1-x}Fe_x$. This x_{comp}-value is very close to the composition at which the sign of $(\partial\omega/\partial H)$ changes. The $(\partial\omega/\partial H)$ value for $R_{0.2}Fe_{0.8}$ at 77 K increases in the order of Dy <Gd <Pr <Nd < Y.

4. Discussion

In rare earth metal(R)-transition metal (TM) alloys and compounds, the magnetic moment of TM elements is induced by the molecular field [1, 2, 5]. The Fe magnetic moment at low temperatures can be written [5] as

$$m_{Fe} = m_{Fe}(0) + \chi(\pm H + J_{FeFe} m_{Fe} + J_{FeR}\langle J\rangle), \quad (1)$$

where m_{Fe} is the Fe magnetic moment, $m_{Fe}(0)$ the Fe magnetic moment in a zero magnetic field, χ the susceptibility, $\langle J\rangle$ the thermal average of the R moments, and J_{FeFe} and J_{FeR} are the molecular field coefficients from Fe and R subnetworks. The sign for H in the parenthesis corresponds to whether H is parallel or anti-parallel to m_{Fe} in ferrimagnets (or sperimagnets). The forced volume magnemtostriction is attributed to the volume expansion due to the increase of Fe magnetic moments in applied fields, given by $(\partial\omega/\partial H) = 2\kappa_C m_{Fe}(\partial m_{Fe}/\partial H)$, and is rewritten as

$$(\partial\omega/\partial H) \cong \frac{2\kappa_C m_{Fe}(0)\chi(\pm 1 + J_{FeR}(\partial\langle J\rangle/\partial H))}{(1-\chi J_{FeFe})}, \quad (2)$$

where κ_C is the magnetovolume coupling constant. The first term in the parenthesis gives to a change of a sign of $(\partial\omega/\partial H)$ in ferrimagnets (or sperimagnets) and the second one which comes from molecular fields of R-subnetworks (H_R) makes a positive contribution to $(\partial\omega/\partial H)$. As can be seen in the figure 3, the sign of $(\partial\omega/\partial H)$ of Dy-Fe and Gd-Fe changes around x_{comp}. This suggests that the second term in equation (2) (hence the induced Fe moment due to H_R in Eq. (1)) is negligible.

From these results it could be considered that the large forced volume magnetostriction found in amorphous R-Fe alloys, especially in the Fe rich composition range, originates from only a nature of Fe atoms; namely the R-dependence of $(\partial\omega/\partial H)$ must be considered in terms of a modification of the electronic structure of Fe atoms. Thermal expansion measurements as well as Mössbauer spectroscopy are now in progress to obtain more informations about the origin of the magnetovolume effect in amorphous R-Fe alloys.

[1] Beille, J., Bloch, D. and Voiron, J., *AIP Conf. Proc.* No **29** (1976) p. 123.
[2] Yoshimura, K., Shiga, M. and Nakamura, Y., *J. Phys. Soc. Jpn* **55** (1986) 3585.
[3] Ishio, S. and Takahashi, M., *J. Magn. Magn. Mater.* **50** (1985) 93.
[4] Rhyne, J. J., Schelleng, J. H. and Koon, N. C., *Phys. Rev. B* **10** (1974) 4672.
[5] Buschow, K. H. J., *Rep. Prog. Phys.* **40** (1977) 1179.