MAGNETOSTRICTION OF RAPIDLY QUENCHED AMORPHOUS RARE EARTH-Fe ALLOYS

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Abstract. – The magnetostriction of rapidly quenched amorphous $R_{1-x}Fe_x$ alloys (R = Pr, Nd, Sm, Gd, Tb, Dy, Er and Y: $0.4 < x < 0.9$) has been measured in the temperature range from 77 K to 300 K. The R dependence of the magnetostriction is discussed in terms of the single-ion model.

1. Introduction

The magnetostriction originates from a strain derivative of a magnetic anisotropy energy and then reflects a local atomic short range order in the amorphous state [1, 2]. In contrast with intensive studies about the magnetostriction of transition metal-metalloid amorphous alloys [1, 2], only a few measurements have been carried out so far for amorphous rare earth (R)-transition metal (TM) alloys [3, 5]. Amorphous R-Fe alloys exhibit several interesting features such as an extraordinary coercive force at low temperatures and aspero magnetic character [6], which supposedly relates to a local magnetic anisotropy in the amorphous state, hence to the magnetostriction. The magnetostriction of amorphous R-Fe alloys is therefore quite interesting from such a physical view-point, as well as from a search for a giant magnetostrictive material.

2. Experimental

Amorphous $R_{1-x}Fe_x$ alloys were prepared by a rapid quenching in an argon atmosphere, where R is Pr $(0.5 \leq x \leq 0.89)$, Nd $(0.5 \leq x \leq 0.83)$, Gd$(0.5 \leq x \leq 0.8)$, Dy $(0.4 \leq x \leq 0.85)$, Sm $(x = 0.8)$, Tb $(x = 0.8)$, Er $(x = 0.8)$ and Y $(0.4 \leq x \leq 0.8)$. They were formed into ribbon, about 1 mm and 10-20 μm thick [5].

The magnetostriction was measured by a three terminal capacitance method in magnetic fields up to 20 kOe and in the temperature range from 77 K to 400 K. This method enables us to measure the magnetostriction using only a sheet of ribbon with 7 mm length even in brittle R-Fe amorphous ribbons [5]. Although the magnetostriction $\lambda = 2/3\left(\lambda_{\parallel} - \lambda_{\perp}\right)$ for $Gd_{1-x}Fe_x$ and $Nd_{1-x}Fe_x(0.78 \leq x \leq 0.83)$ shows a saturation at $H < 5$ kOe in all the temperature range, λ's for the others exhibit a sluggish increase up to 20 kOe. The maximum field applied was 20 kOe, so the magnetostriction λ at 20 kOe is reported in this paper instead of saturation magnetostriction λ_s.

3. Experimental results and discussion

The temperature dependence of λ for $R_{0.2}Fe_{0.8}$ alloys is shown in figure 1. The Curie temperatures of these alloys range from 277 K for R = Er to 504 K for R = Gd. The values of λ for R = Pr, Sm and Gd are about 630, – 400 and 13×10^{-6} at 77 K, respectively, and decrease monotonically with heating. λ for R = Nd changes a sign from negative to positive at about 100 K with increasing temperature. A compensation of magnetization takes place at about T = 210 K for R = Dy and at T < 77 K for Tb and causes a hysteretic λ-H curve at temperatures below T_{Hc}, resulting in an apparent decrease of λ (see Fig. 1). Here T_{Hc} is defined as the temperature below which $\lambda - H$ curves become irreversible even above 10 kOe. Hysteretic λ-H curves were also observed in R = Pr, Nd and Dy alloys with $x \leq 0.7$: these are attributed to an extraordinary coercive force at low temperatures [6].

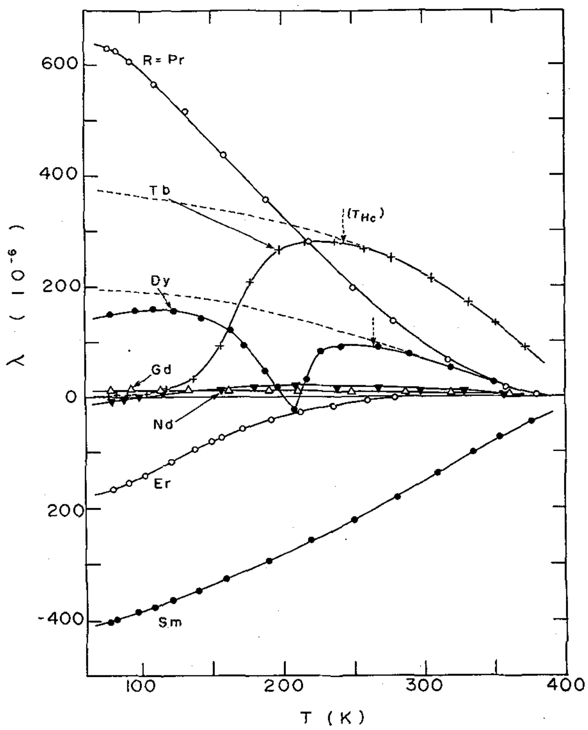

Fig. 1. – Temperature dependence of λ at 20 kOe for amorphous $R_{0.2}Fe_{0.8}$ alloys. For the broken lines and T_{Hc}, see text.

The composition dependence of λ for $R_{1-x}Fe_x$ (R = Nd, Pr, Gd and Dy) at 77 K is plotted in figure 2. The λ -values having error bars in the figure were obtained by an extrapolation from data above T_{Hc}. A few examples of extrapolation are drawn by broken lines in figure 1. Note that λ for R = Pr, Nd and Dy takes a maximum at x =0.7-0.8.

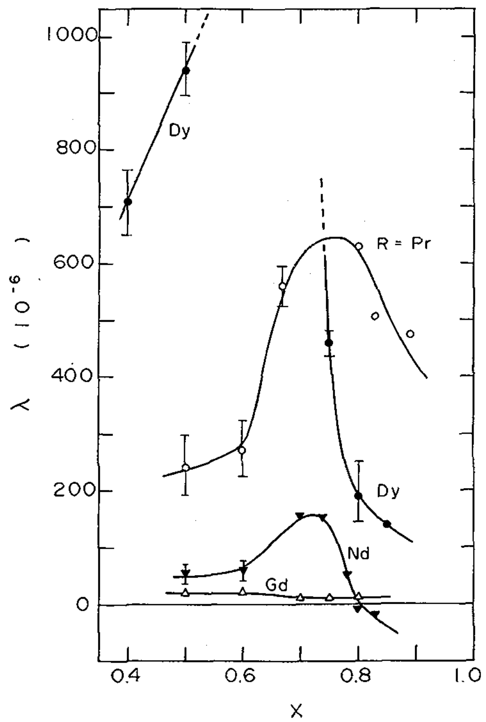

Fig. 2. – Concentration dependence of λ at 77 K for amorphous $R_{1-x}Fe_x$ alloys.

The values of λ at 77 K of $R_{0.2}Fe_{0.8}$ are plotted against R elements in figure 3. The magnetostriction of both R-Fe amorphous alloys and compounds is considered to originate from a uniaxial distortion of an atomic short range order (SRO) surrounding R atoms and was discussed in terms of the single-ion model so far [4, 7]. According to this model, a ratio of the magnetostriction of one lanthanide ion to another is given by the ratio of $\alpha J\,(J-1/2)\left\langle r_f^2\right\rangle$, where α is the lowest order Stevens' factor, J the ground state angular moment for 3^+ ions and $\left\langle r_f^2\right\rangle$ is the average radius squared of the 4f electron shell. The value of $\alpha J\,(J-1/2)\left\langle r_f^2\right\rangle$ is indicated by solid lines in the figure, normalized by λ of R = Pr. Note that the experimental values of λ agree well to the theoretical expectation. It is therefore obvious that the magnetostriction of the amorphous R-Fe alloys originates from the single-ion model type coupling between the angular moment of R elements and the crystal field surrounding R elements. The further implication is that SRO around R is almost equal through amorphous R-Fe alloys with $x = 0.8$.

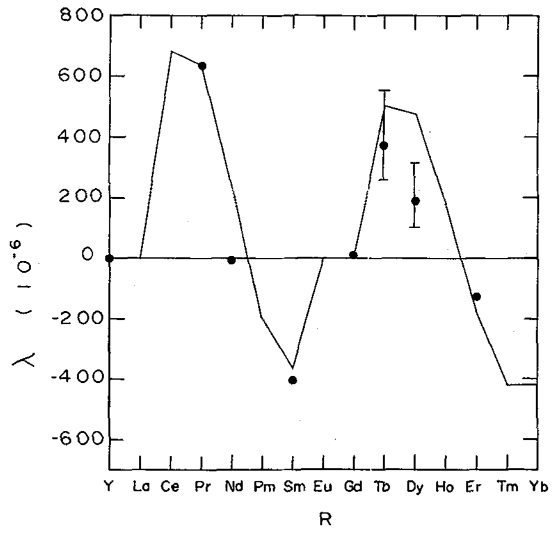

Fig. 3. – λ at 77 K as a function of the lanthanide element R for amorphous $R_{0.2}Fe_{0.8}$ alloys.

On the other hand, the composition dependence of λ of Pr, Nd, Dy-Fe exhibits the maximum at about x = 0.7 as seen in figure 2. This behaviour is quite similar to those of R-Fe compounds [4]. This may indicate a similarity of SRO around R elements between the R-Fe amorphous alloys and their compounds. Hence the change of SRO in the amorphous state supposedly causes the composition dependence of λ in amorphous $R_{1-x}Fe_x$ alloys.

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