AIP Journal of Applied Physics

Measurement of the saturation magnetostriction constant of amorphous wire

A. Mitra and M. Vázquez

Citation: Journal of Applied Physics **67**, 4986 (1990); doi: 10.1063/1.344698
View online: http://dx.doi.org/10.1063/1.344698
View Table of Contents: http://scitation.aip.org/content/aip/journal/jap/67/9?ver=pdfcov
Published by the AIP Publishing

Measurement of the saturation magnetostriction constant of amorphous wire

A. Mitra
Instituto de Magnetismo Aplicado RENFE-UCM and Departamento de Fisica de Materiales, Universidad Complutense, 28040 Madrid, Spain

M. Vázquez
Instituto de Magnetismo Aplicado RENFE-UCM and Departamento de Fisica de Materiales, Universidad Complutense, 28040 Madrid, Spain and Instituto de Ciencias de Materiales (CSIC), Serrano 144, 28006 Madrid, Spain

Measurement of the magnetostriction constant of amorphous wire by conventional techniques is very difficult because of its small diameter. However, accurate determination of the magnetostriction constant is important in the study of amorphous wires. Here the saturation magnetostriction constant (λ_s) for a low-magnetostriction amorphous wire of nominal composition $(Fe_{6.3}Co_{92.7}Nb_1)_{77.5}Si_{7.5}B_{15}$ has been determined by means of the small-angle magnetization-rotation method. λ_s has been evaluated to be 2.1×10^{-7} for its as-received state. The dependence of thermal treatment is also reported.

I. INTRODUCTION

The anisotropy of the amorphous magnetic alloys is mainly magnetoelastic in origin. As a result, its magnetic properties depend very much on the magnetostriction constant. So the accurate determination of the saturation magnetostriction constant (λ_s) is important to study amorphous ferromagnets. It is very difficult to measure the magnetostriction constant of amorphous wires with strain-gauge or three-terminal-capacitance methods because of its small diameter (125–50 μm). The small-angle magnetization-rotation (SAMR) method is a very useful technique to measure the λ_s of this type of material and is successfully applied in the case of amorphous ribbons.[1] Konno and Mohri[2] argued that this SAMR method is not suitable for amorphous wires because it generates a strong demagnetizing field. In the present work we have studied whether the magnetostriction constant of the wire can be measured by the SAMR method. We have also studied the annealing behavior of the magnetostriction constant of the wire.

II. THEORY

The small-angle magnetization rotation is caused by the simultaneous application of a small-amplitude ac drive field, H_y, and a high dc bias field, H_z, perpendicular and parallel to the axis of the wire, respectively. The dc bias field must be high enough to produce magnetization saturation. The induced voltage due to the magnetization rotation, sensed by the coil wound around the sample, is the second harmonic of the applied ac drive field and is given by

$$V_{2f}^2 = \text{const} \times H_y^{\max}/(H_z + H_k + H_s). \qquad (1)$$

Here, $H_k = 3\lambda_s\sigma/\mu_0 M_s$ is the stress-induced anisotropy, where λ_s is the saturation magnetostriction constant, M_s is the saturation magnetization, and σ is the stress applied to the sample. H_s is the shape-induced anisotropy. Under a change of applied stress, the modification of the anisotropy field results in a change of the pickup voltage V_{2f} which can be compensated by a convenient modification of the bias field H_z. This change of bias field to keep V_{2f} constant is a direct measure of the stress-induced anisotropy field H_k, due to applied stress. Measuring H_k at different values of stress, one can estimate the saturation magnetostriction constant using the relation

$$\lambda_s = (\mu_0 M_s/3)(\Delta H_k/\Delta\sigma). \qquad (2)$$

III. EXPERIMENT

The sample used in the present work is $(Fe_{6.3}Co_{92.7}Nb_1)_{77.5}Si_{7.5}B_{15}$, which was supposed to exhibit a low λ_s value. Its length and diameter are 10 cm and 125 μm, respectively; the sample was obtained by use of the in-water quenching technique.[3] A dc bias field is applied in the longitudinal direction and a perpendicular ac drive field has been generated by passing a current through the wire, which produces a field of less than 1 Oe at the surface. The pickup voltage is measured by a lock-in amplifier (PAR-5209).

IV. RESULTS AND DISCUSSION

The basic assumptions of the SAMR method are (i) the sample must be in a saturation-magnetization state, and (ii) the magnetoelastic anisotropy ($\frac{3}{2}\lambda_s\sigma$) has to be the same everywhere within the sample. In Fig. 1 the induced pickup voltage (V_{2f}) is plotted as a function of applied stress with the applied field as a parameter. Figure 2 shows $1/\sqrt{V_{2f}}$ plotted against the bias field for different applied stress, keeping the transverse field constant. The behavior agrees well with Eq. (1) only at high bias field. The dc bias field beyond which the SAMR method is suitable is determined by the values $V_{2f}H_z^2$.[4] The applied dc bias field should be high enough so that $V_{2f}H_z^2$ is constant. In Fig. 3 we have plotted $V_{2f}H_z^2$ against H_z, and the inset of Fig. 3 shows the M-H_z curve. It is seen from Fig. 3 that the bias field for the (FeCoNb)SiB wire must be higher than 3 Oe to be sure one is in the saturation region. The dc bias-field dependence of $1/\sqrt{V_{2f}}$ is shown in Fig. 4 for different transverse drive fields.

0021-8979/90/094986-03$03.00

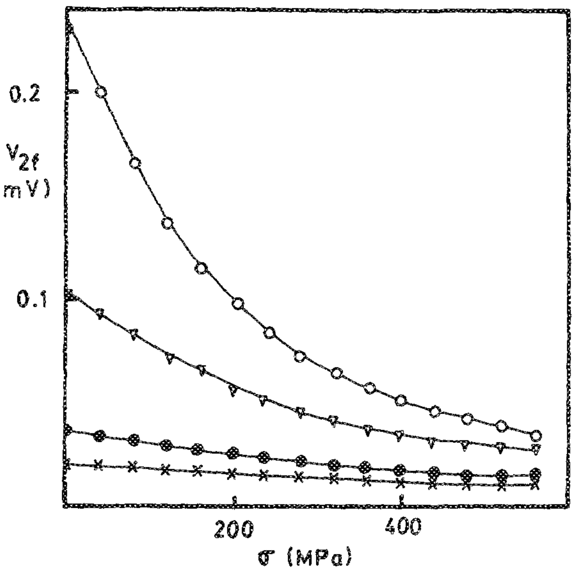

FIG. 1. Induced pickup voltage (V_{2f}) plotted against stress (σ) at different bias fields: (○) 2.1, (▽) 3.5, (⊛) 7.0, and (×) 10.5 Oe.

As seen from Eq. (1), the extrapolated values cross each other at the shape-anisotropy field of the sample, which is 2.2 Oe for the (FeCoNb)SiB amorphous wire. In Fig. 5 the induced anisotropy field H_k is plotted against the applied stress for different annealed (FeCoNb)SiB wires. The applied dc bias field is 45 Oe and the ac drive field at the surface is 0.67 Oe. Annealing is done at 450 °C for different durations of time in an argon atmosphere. Assuming saturation magnetization of 7.12 kG,[5] λ_s is calculated from the slope of the H_k-σ curve. The annealing behavior of λ_s is plotted in the inset of Fig. 5. λ_s increases with the annealing time at the beginning, but decreases after 30 min of annealing. The decrease of λ_s for longer annealing times may be due to the

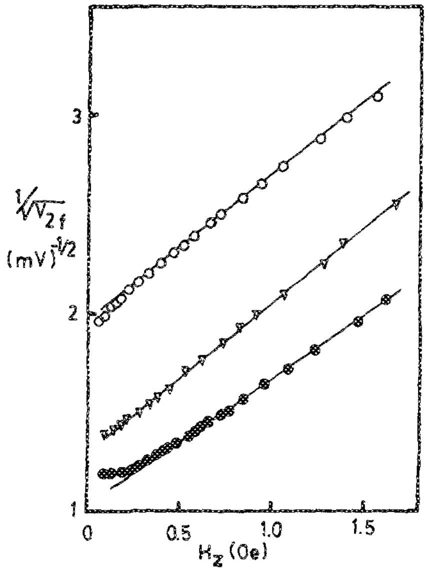

FIG. 2. $1/\sqrt{V_{2f}}$ plotted as a function of the longitudinal field H_z for a range of applied stresses σ: (⊛) 80, (▽) 160, and (○) 280 MPa. Drive field at the surface is constant: $H_y^{\max} = 0.67$ Oe.

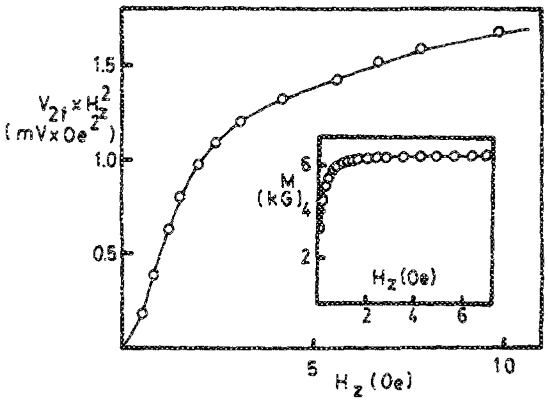

FIG. 3. Dependence of $V_{2f}H_z^2$ on H_z. Inset shows the longitudinal magnetization curve.

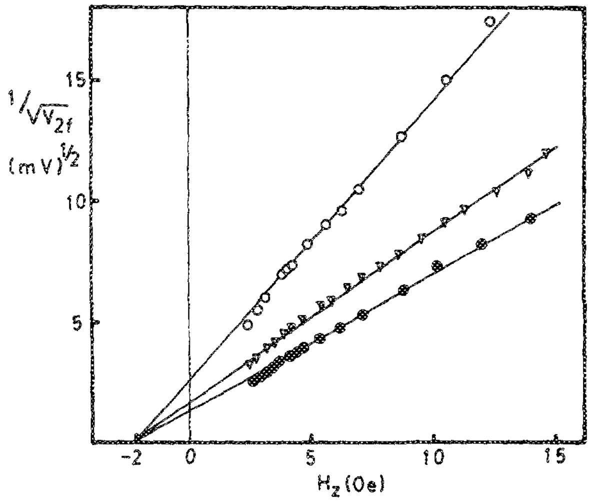

FIG. 4. $1/\sqrt{V_{2f}}$ as a function of H_z for different drive fields at the surface of the wire. $H_y^{\max}$ = (⊛) 0.67, (▽) 0.50, and (○) 0.34 Oe, without any applied stress.

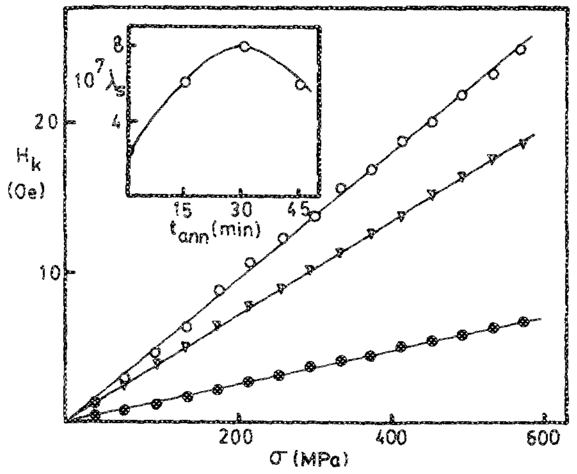

FIG. 5. Dependence of the anisotropy field H_k on the applied stress after annealing at 450 °C during $t_{\rm ann}$ = (⊛) 0, (▽) 15, and (○) 30 min. Insert shows the obtained dependence of λ_s with annealing time.

development of a microcrystalline structure inside the amorphous matrix. Although the SAMR method is successfully applied to the low-magnetostriction wire, the application of this method for higher-magnetostriction wires will cause trouble because of the second basic assumption of the validity of this method. The high-magnetostriction amorphous wires have two distinct anisotropy regions—transverse and longitudinal—produced during preparation by the in-water quenching technique.[5] However, by eliminating this inhomogeneous distribution of anisotropy regions after proper annealing, the SAMR method could be a useful technique for magnetostriction measurements on high-magnetostriction wires also.

V. CONCLUSIONS

We have successfully measured the magnetostriction constant of low-magnetostriction $(Fe_{6.3}Co_{92.7}Nb_1)_{77.5}Si_{7.5}B_{15}$ amorphous wires by use of the small-angle magnetization-rotation method. However, this method is not suitable for high-magnetostriction wires because of its peculiar distribution of internal stresses, which produce two distinct anisotropic regions inside the wires. After proper annealing, which removes the internal stresses, this method may also be suitable for determination of the magnetostriction constant for high-magnetostriction wires.

[1] K. Narita, J. Yamasaki, and H. Fukunaga, IEEE Trans. Magn. **MAG-16**, 435 (1980).

[2] Y. Konno and K. Mohri, IEEE Trans. Magn. **MAG-25**, 3623 (1989).

[3] I. Ohnaka, T. Fukusako, and T. Daido, J. Jpn. Metall. **45**, 751 (1981).

[4] A. Hernando, M. Vázquez, V. Madurga, E. Ascasibar, and M. Liniers, J. Magn. Magn. Mater. **61**, 39 (1986).

[5] A. Mitra and M. Vázquez, J. Phys. D. (in press).