Proceedings of the 2nd EAA International
Symposium on Hydroacoustics
24-27 May 1999, Gdańsk-Jurata
POLAND

Piezomagnetic Dynamics and Magnetomechanical Coupling in Fe-Co-Ni-Zr-Cu-Nb-B Amorphous Alloy

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Magnetic field dependences of the piezomagnetic dynamics and the magnetomechanical coupling on the heat-treatment and magnetic bias field in the $Fe_{62.5}Co_6Ni_{7.5}Zr_6Cu_1Nb_2B_{15}$ alloy strips were investigated. The magnetomechanical coupling coefficient increased from 0.10-0.12 for as-quenched samples to 0.38 after annealing at 390°C.

1. Introduction

Metallic glasses are the very intensive developed group of the magnetic materials. Among them the iron-rich alloys have a high enough magnetostrictiction (above 20 x 10^{-6}) for ultrasonic applications [1-3,5]. After a special heat-treatment below the crystallization temperature these alloys exhibit the saturation magnetostrictiction in the range (20-30) x10^{-6} and promissing piezomagnetic and ultrasonic properties [1-3, 5,13-16,18].

In the best soft magnetic materials, as are Finemet-type alloys, e.g. $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$, is obtained nanocrystalline structure after annealing above 550°C [18] .

The Finemet-type alloy in as-quenched state and after annealing in the temperature range up to about 470°C is amorphous · metallic glass with the saturation magnetostriction equal to (20-26) x 10^{-6} [5, 15,16,18].

The results of the piezomagnetic and ultrasound investigations in the Finemet-type alloy were presented in some previous papers, e. g. [15,16].

In the Finemet-type alloy, instead silicium and except niobium, iron and boron, other elements may be substituted, e.g. zirconium, nickel and cobalt [14].

The aim of this work was to compare the results for the as-quenched samples with those received after annealing in vacuum at the temperature range from 350 to 390°C for the piezomagnetic dynamics [8,9] and for the magnetomechanical coupling coefficient [4-6,11] in $Fe_{62.5}Co_6Ni_{7.5}Zr_6Cu_1Nb_2B_{15}$ alloy strips [14].

2. Piezomagnetic Dynamics and Magnetomechanical Coupling

The properties of piezomagnetic materials and transducers are characterized by the piezomagnetic coefficients in piezomagnetic equations, e.g. [4-6, 11,12,17], and by other magnetomechanical and physical parameters and quantities. The most important are: the magnetomechanical coupling coefficient (k) [4-6,8-13,16,17], the mechanical, magnetic (electrical) and magnetomechanical quality factors [Q_m , Q_μ (or Q_e), Q_H and Q_B] [5,6,10,11,17] and the piezomagnetic dynamics (Z_d) [8-11].

The magnetomechanical coupling coefficient (k) is a measure of the effectiveness of energy conversion and with the mechanical, magnetic and magnetomechanical quality factors, and the electroacoustical efficiency, vibration amplitude, Curie temperature etc., allows a comparison of properties of the piezomagnetic materials and transducers with the properties of the other piezomagnetic or piezoelectric materials or transducers, e.g. [17].

Both, the magnetomechanical coupling coefficient (k) and the piezomagnetic dynamics (Z_d) were obtained from the resonant-antiresonant characteristics of impedance [5,6,8-12].

3. Experimental

The amorphous ribbons were produced from the melt using rapidly quenched method. Strip-shape samples were cut from the ribbon of the $Fe_{62.5}Co_6Ni_{7.5}Zr_6Cu_1Nb_2B_{15}$ metallic glass [14].

The strips were 40 mm long, 2 mm wide and about 22 μm thick [14].

In this alloy except iron were other ferromagnetic elements, i.e. cobalt and nickel, and, as in the Finemet-type alloys [5,15,16,18], also niobium, copper and boron. Zirconium was as an additional element and silicon was absent.

One strip was measured in as-quenched state, and the others - after annealing for 1 h in vacuum at different temperatures changed from 350 to 390°C, i. e. at 350, 370, 380 and 390°C.

The magnetomechanical coupling coefficient (k) was determined from the resonant (f_r at the maximum impedance Z_{max}) and the antiresonant (f_a at the minimum impedance Z_{min}) frequencies (Fig. 1), using the following equation for the half-wave resonator [4-6,11,12,17]:

$$k \approx (\pi/2)(1 - f_r/f_a)^{1/2}. \quad (1)$$

The piezomagnetic dynamics (Z_d) was determined from the difference between the maximum impedance Z_{max} and the minimum impedance Z_{min}) [9-11], i.e.:

$$Z_d = Z_{max} - Z_{min}. \quad (2)$$

The magnetic field dependences of the piezomagnetic dynamics and magnetomechanical coupling coefficient were investigated in as qyenched sample and in the annealed up to 390°C strips.

The resonat frequencies were observed in the range from about 47 to 58 kHz.

The amplitude of the exciting AC magnetic field was equal to about 2A/m

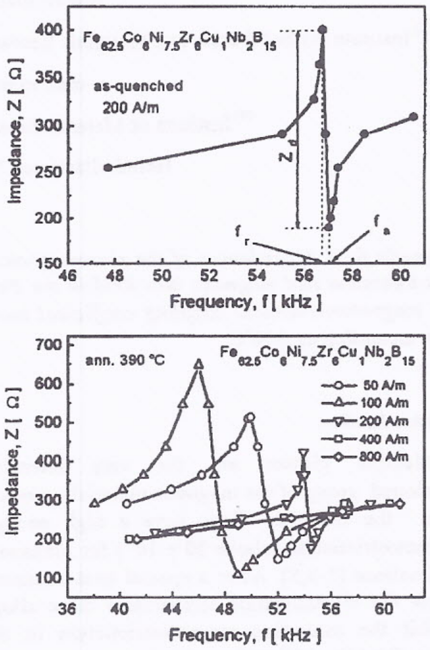

Fig. 1. Moduli of impedance (Z) versus frequency (f) at magnetic bias field H = 200 A/m for as-quenched sample and at H = 50, 100, 200, 400 and 800 A/m for the annealed in vacuum for 1 h at the temperature 390°C strips.

4. Results

The magnetic field dependences of the piezomagnetic dynamics and magnetomechanical coupling as the functions of the magnetic bias field were investigated for the as-quenched and annealed samples.

The magnetic bias field was changed from 20 A/m to nearly technical saturation (1200 A/m for the as-quenched samples(Fig. 2) and to 500-700 A/m for the annealed samples (Figures 2 and 3).

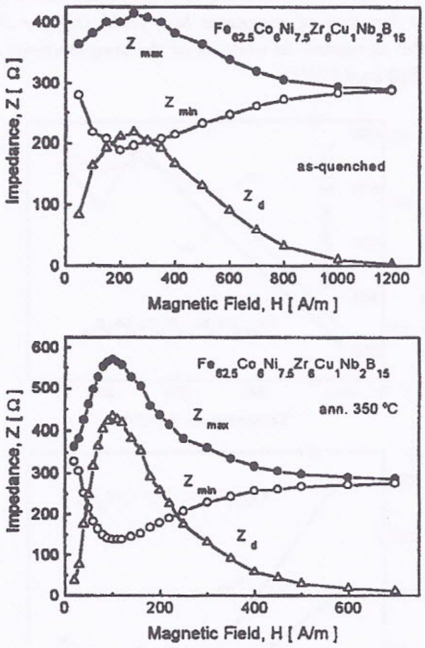

Fig. 2. The Z_{max} and Z_{min} impedances and the piezomagnetic dynamics (Z_d) vs. magnetic bias field (H) for as-quenched and annealed at 350°C samples.

The dependence of the maximum (Z_{max}) and minimum impedances (Z_{min}) and the piezomagnetic dynamics (Z_d) *vs.* the magnetic bias field (*H*) for the as-quenched sample and for the samples annealed at the temperatures of 350, 370, 380 and 390°C are presented in Figures 2 and 3.

Also the characteristics of the piezomagnetic dynamics (Z_d), obtained from equation (2), i.e. from the differences between the maximum (Z_{max}) andminimum impedances (Z_{min}), and the magnetomechanical coupling coefficient (*k*),

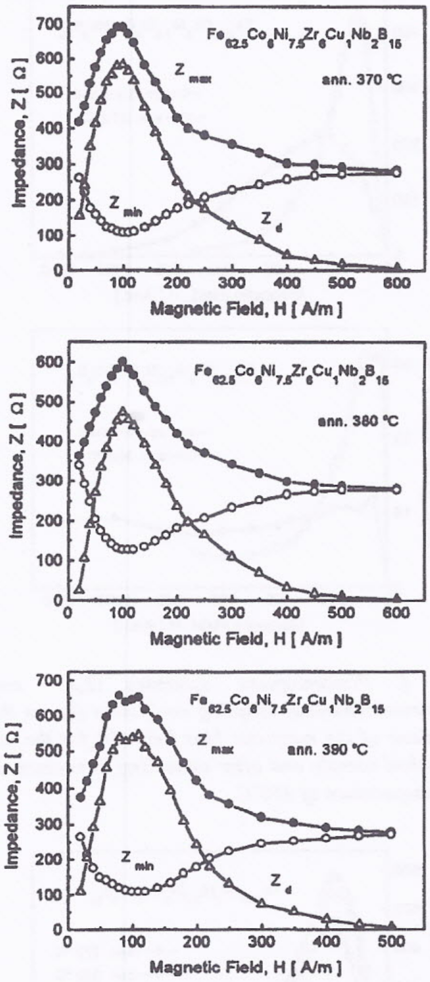

Fig. 3. The maximum (Z_{max}) and minimum impedances (Z_{min}) and the piezomagnetic dynamics (Z_d) vs. the magnetic bias field (H) for annealed at the temperatures of 370, 380 and 390°C.

calculated from equation (1), as a functions of the magnetic bias field (*H*) for the same samples are presented in Figures 4-6.

The characteristics of the maximum values of the piezomagnetic dynamics (Z_{dm}) and magnetomechanical coupling coefficient (k_m) as the funtions of the annealing temperature (*T*) are presented in Fig. 7.

At the left side (for 20°C) are given the values of the Z_{dm} and k_m for as-quenchedsamples (as-q.). Below, in Fig. 7, there are given also values of the bias magnetic fields (*H*) at which these maxima of

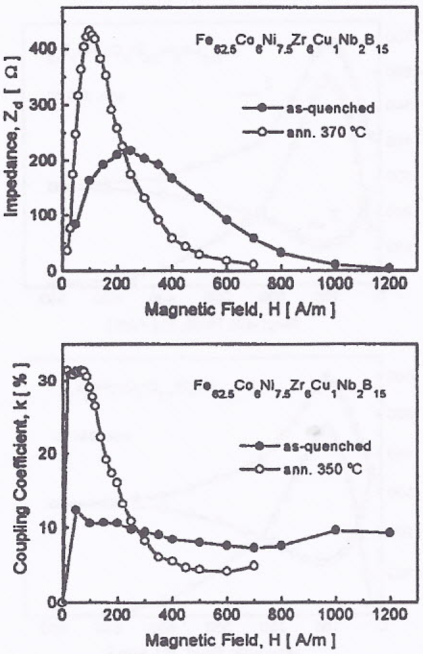

Fig. 4. Piezomagnetic dynamics (Z_d) and magnetomechanical coupling coefficient (k) as the functions of the magnetic bias field (H) for the as-quenched sample and after annealing in vacuum at the temperature of 350°C.

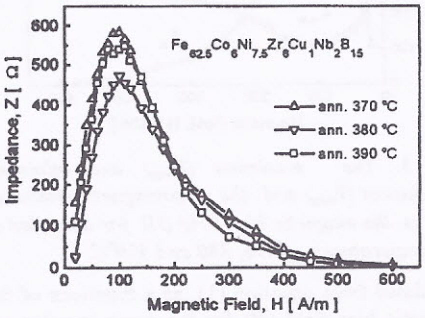

Fig. 5. Piezomagnetic dynamics (Z_d) as the function of the magnetic bias field (H) for the samples after annealing in vacuum at the temperatures of 370, 380 and 390°C

the piezodynamics (Z_{dm}) and of the k_m coefficient occured.

The scale is common for and the bias fields H_{Zdm} and H_{km} .

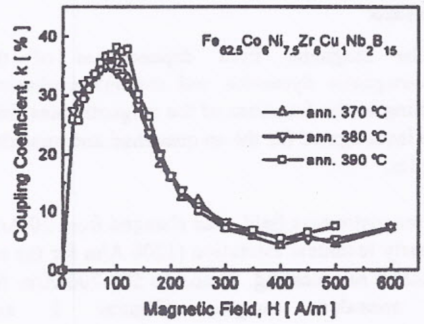

Fig. 6. Magnetomechanical coupling coefficient (k) as the function of magnetic bias field (H) for the samples annealed in vacuum at the temperatures of 370, 380 and 390°C.

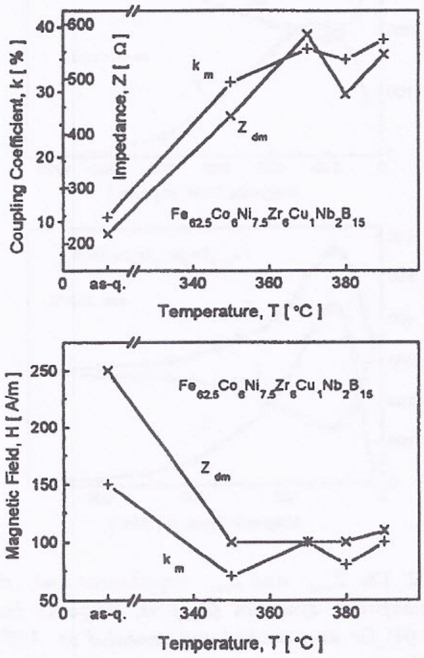

Fig. 7. The maxima of the piezomagnetic dynamics (Z_{dm}) and of the magnetomechanical coupling coefficient (k_m) as the functions of the annealing temperature (T).

5. Discussion

The piezomagnetic dynamics and the magnetomechanical coupling coefficient in the piezomagnetic materials are not the material constants but depend on the magnetic field, annealing time, temperaturetre and atmosphere, and mechanical, magnetic and heat-treatment histories. In the ivestigated range both parameters were increasing with increas of the annealing temperature.

The magnetomechanical coupling coefficient increased from 0.10-0.12 for the as-quenched sample (Fig. 4) to 0.38 after annealing at 390°C (Fig. 6).

This last value of the k coefficient is higher than that in the classical nickel (0.20-0.32).

The optimum values of the bias magnetic field for the maximum of the magnetomechanical coupling coefficient decreased from 150 A/m for as-quenched sample (Figs. 2, 4 and 7) to 70-100 A/m for the annealed samples in the temperature range from 350 to 390°C (Figs. 2-5 and 7).

The nonregularities in the H_{km} values (Fig. 7) are connected with two resonances observed in more of the investigated samples.

The characteristics of the piezomagnetic dynamics (Z_d) as the functions of the magnetic bias field (H) exhibit maxima from 200 (for the as-quenched sample, Figs. 2, 4 and 7) to 440 to 580 Ω (for the annealed samples, Figs. 2-4, 7) at the magnetic bias field from 100 A/m to 250 A/m (for the as-quenched samples).

The optimum values of the magnetic bias fields (H) for maximum of the magnetomechanical coupling coefficient (k) after annealing were something lower than those for the piezomagnetic dynamics of the annealed samples and much lower than those for the as-quenched state.

6. Conclusions

- The annealed at the temperatures from 350 to 390°C $Fe_{62.5}Co_6Ni_{7.5}Zr_6Cu_1Nb_2B_{15}$ alloy strips exhibit the better magnetomechanical coupling than classical nickel.

- The optimum bias field for the maximum of of the magnetomechanical coupling coefficient for as-quenched samples was equal to about 50-200 A/m and after annealing above 350°C decrease to 70-110 A/m.

- The optimum bias field for the maximum of of the piezomagnetic dynamics for as-quenched samples was equal to about 250 A/m and after annealing above 350°C decrease to about 100 A/m.

- The maximum values of the piezomagnetic dynamics for as-quenched samples were equal to about 200 Ω and the maximum of the piezomagnetic dynamics for annealed samples were equal to 440 to 580 Ω.

- This type of alloy in the amorphous state may be used in the magnetostrictive delay lines or for the cores of the ultrasound transducers [1,17].

Acknowledgement

The authors thank Mr. Andrzej Krzyżewski from the Polish Academy of Sciences Institute of Physics for the technical assistance.

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