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Characterization of Joule-heated Co-rich amorphous alloys under applied tensile stress by the inductance spectroscopy method

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Abstract

The inductance response of stress-annealed (1.55 A for 5 min, with tensile stress in the 300–615 MPa range) amorphous ribbons of Vitrovac® 6025 was measured by applying an AC magnetic field (5 Hz–13 MHz) in the longitudinal and transverse axis. Results can be interpreted in terms of a combination of axial domains isolated and surrounded by a fine system of transverse domains.

Keywords: Domain structure; Magnetostriction; Stress-annealings; Impedance measurements

Recently, the magnetoimpedance effect (MI), i.e., the variations in the impedance response of a ferromagnetic material submitted to an AC current of small amplitude when a DC magnetic field is applied, has been observed in Co- and Fe-based amorphous samples (wires, ribbons and films) [1–3]. Since MI is based on the coupling of the AC magnetic field (produced by the AC current) with the magnetic structure of the material [4], the magnetic permeability and the transverse magnetic structure play the most important role.

Co-based amorphous alloys, due to their high permeability and small and negative magnetostriction are among the most suitable materials to investigate the dependence of magneto-impedance effect on the transverse domain structure. A variety of transverse domain structures can be effectively produced in these alloys by means of stress-annealing techniques, via magnetoelastic interactions.

In the present work, we propose the inductance spectroscopy method [4,5] as a very useful technique in order to distinguish and evaluate the influence of the applied tensile stress on the domain wall structures induced in Joule-heated samples of Co-rich amorphous alloys.

Amorphous ribbons of Vitrovac 6025 (kindly provided by Dr. G. Herzer, Vacuumschmelze GmbH, Germany) with nominal composition $Co_{66}Fe_4Mo_2B_{16}Si_{12}$ (10 cm long, 3 mm wide, 20 μm thick) were current annealed by applying a current 1.55 A during 5 min time under applied tensile stresses ranging from 300 to 615 MPa, in order to induce creep magnetic anisotropy. As-cast and annealed samples were analysed by X-ray diffraction.

The complex inductance response was measured in the transverse and longitudinal directions with respect to the ribbon axis in the frequency range 5 Hz to 13 MHz by means of a system including a HP4192A impedance analyzer. For the transverse geometry measurements, samples were directly submitted to the AC current from

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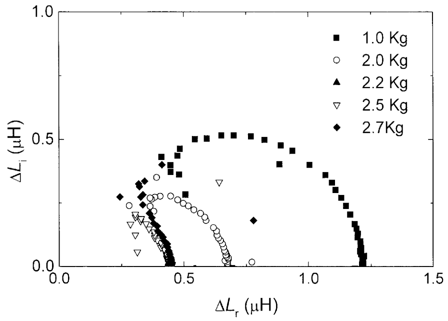

Fig. 1. Complex inductance plots of samples measured in the logitudinal geometry for different tensile stress, as shown by the weight applied during annealing.

the impedance analyzer by making electrical contacts as explained elsewhere [6]. Longitudinal magnetization measurements were performed by using a 80-turn solenoid to apply the AC magnetic field. Both types of measurements were carried out under a zero and a DC applied field of 80 Oe. All the results presented here were obtained by subtracting the high DC field value from the zero field point by point, for the measurement at each frequency:

$$\Delta L_r = L_{r(H\ DC=0)} - L_{r(H\ DC=80\ Oe)}, \quad (1)$$

$$\Delta L_i = L_{i(H\ DC=0)} - L_{i(H\ DC=80\ Oe)}, \quad (2)$$

where L_r and L_i are the real and imaginary parts of the inductance, derived from complex impedance by $L = (-j/\omega)Z$, with ω = angular frequency and $j = (-1)^{1/2}$. We have recently shown [6] that this procedure allows to retain the domain wall permeability and eliminates the contribution from spin rotation processes.

Complex plots of inductance in the longitudinal geometry showed the tendency to form a semicircle, Fig. 1; the measuring frequency increases from the right-hand side toward the left-hand side on the L_i-axis. This behavior is associated [4–6] with the relaxation of pinned domain walls, which become unable to follow the excitation field as its frequency increases. As the tensile stress applied during annealing increases, the semicircles' diameter decreases, leading to a decrease in longitudinal permeability.

Similar experiments in the MI transverse geometry produced also a tendency to form semicircles in the complex inductance representation, Fig. 2. Some differences appear, however. First, the semicircles do not close in the low-frequency end, but show a "spike", leading to high values in the imaginary part of inductance. Also, the diameter of semicircles exhibits a closer distribution about a value five times smaller than the highest value of the longitudinal case.

Since the diameter of semicircles decreases with applied weight in the case of longitudinal measurements, it follows that the increase in stress leads to an increase in the relative volume of transverse domain. In contrast, transverse domains have a finer structure, which is apparent from the smaller diameter shown in Fig. 2. These transverse domain walls are much more mobile than the longitudinal ones, as far as they exhibit an almost vertical spike, directly related with an unpinning and displacement mechanism [7]. As the stress increases, creep-induced anisotropy increases, and the position of the spike decreases, Fig. 2. The transverse permeability decreases, since it is proportional to the real inductance.

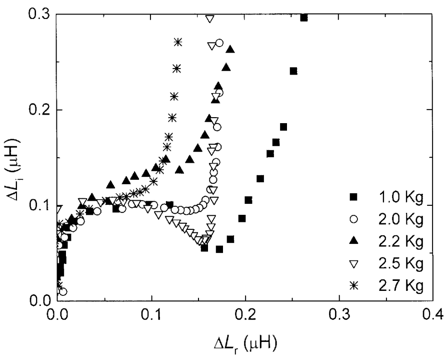

Fig. 2. Complex inductance plots of samples measured in the transverse (or MI) geometry for different tensile stress, as shown by the weight applied during annealing.

All the results lead therefore to a complicated pattern of longitudinal and transverse domain wall structures. Longitudinal walls are larger than the transverse ones, and are more tightly pinned than the latter. On the other hand, transverse walls have a finer structure (are smaller) and are more loosely pinned. A magnetic domain structure which can be consistent with these results is formed by few longitudinal walls surrounded by many smaller transverse domain walls. As a general conclusion it can be said that inductance spectroscopy is becoming a sensitive and powerful analysis technique for ferromagnetic materials.

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