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Magnetic field meter based on giant magnetoimpedance effect

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Abstract

The giant magnetoimpedance (GMI) effect in Co-based amorphous ribbon was investigated. In order to improve the properties of its magnetoimpedance characteristics, with respect to their application as a sensing element, the ribbon samples were subjected to various thermal and mechanical treatments. The sample, which exhibited the best performance, was utilized in a laboratory model of a magnetic field meter. The characteristics of the model constructed were measured revealing its high sensitivity and good thermal stability.

Keywords: Giant magnetoimpedance; Metallic glass; Magnetic field sensor

1. Introduction

For soft magnetic materials (in the form of microwires, ribbons, films or composite structures) the dependence of electrical impedance on the magnetic field can be strong when only the frequency of an ac-current flowing along such a magnetic element is sufficiently high [1–3]. This phenomenon, known as the giant magnetoimpedance (GMI) effect, has attracted a great deal of attention due to its possible applications, e.g. in miniaturized magnetic sensors [4–10]. The GMI-effect is strongly dependent on the magnetic structure of the element under consideration and is sensitive to its geometry, structural non-homogeneity and local magnetic anisotropies [4,11,12]. Significant progress has been achieved during the recent years in the theoretical description as well as in the application of the GMI-effect (see e.g. [12,13]). However the design of new materials for applications requires further study leading to a deeper understanding of the interrelation between the magnetic structure and magnetization dynamics. As a result we can expect that new materials with improved properties can be developed [11,12].

In the present work, the GMI-effect was studied in low magnetostrictive Co-based amorphous ribbon, which properties were modified by annealing and also by changing the ribbon dimensions. They were stimulated by the desire to optimize the GMI-effect in the ribbon under the angle of its application as a magnetic sensing element. These modifications have changed the magnetic and magnetoimpedance characteristics of the ribbon mainly due to alterations of magnetic anisotropies.

The primary objective of the present work was to design and construct a sensitive magnetic field meter based on the modified ribbon and utilizing the dependence of impedance on the static field.

In many of magnetoimpedance-based sensors the active magnetic element is a part of the oscillator circuit. This permits to avoid problems such as parasitic displacement currents, impedance mismatching and the presence of reflected signals [7]. The oscillator output signal is usually a nonlinear function of the applied field. A pair of magnetic elements (with opposite bias fields) can give a linear sensor.

The weak magnetic field meter proposed here is based on the variations of the quality factor of the oscillator tank circuit containing a magnetic field sensitive element. These changes are due to alterations of the real component of impedance. The specific design of the meter makes its output practically insensitive to temperature changes (and other instabilities) without the necessity of a differential method (two elements with opposite bias fields) applied in many other solutions [6,7].

2. Experimental

Rapidly solidified amorphous ribbon 25 μm thick and 2.2 mm wide of high permeability alloy of the nominal composition $Co_{67}Fe_4Mo_{1.5}Si_{16.5}B_{11}$ (Vitrovac® 6025) was used in

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the experiments. The Curie temperature of this ribbon was around 200 °C, as determined from thermo-magnetic measurement [14]. Its saturation magnetostriction was extremely low ($\lambda_S < 10^{-7}$), as estimated by strain-modulated ferromagnetic resonance method (SMFMR) [15]. The samples used in the experiments were: (i) 60 mm long and 2.2 mm wide (denoted as L1–L5), (ii) 35 mm long 2.2 mm wide (S1–S6) and (iii) 35 mm long 1.0 or 0.5 mm wide (N1, N2). These samples were cut out along their length using a wire-saw. The annealing was performed in an evacuated quartz ampoule (to prevent oxidation) for 1 h at a selected temperature in the range 200–300 °C.

The auto-balancing bridge (Agilent model 4285A) with four coaxial leads (four-pair method) was used to measure two components of the impedance, in the frequency range 100 kHz to 30 MHz of the ac-current of the intensity up to 20 mA (rms). The facility was equipped with the so-called cable compensation function (open/short/load correction) which has allowed to eliminate the errors introduced by 1 m long cables and to keep constant the level (auto level function) of the sinusoidal current. The designed sample-holder (see Fig. 1) was equipped with four gold tip contacts (the voltage pick-up contacts were placed 19 mm away). The sample was pressed to the contacts by a plate (with a rubber layer) which was held down by four springs. The errors introduced by the sample-holder were determined measuring the impedance of the thin copper short-circuiting plate. The facility described was computer controlled, thus enabling to measure precisely the magnetoimpedance characteristics, in an axial static magnetic field of the intensity up to 12 kA/m (regulated range) supplied by a pair of Helmholtz coils.

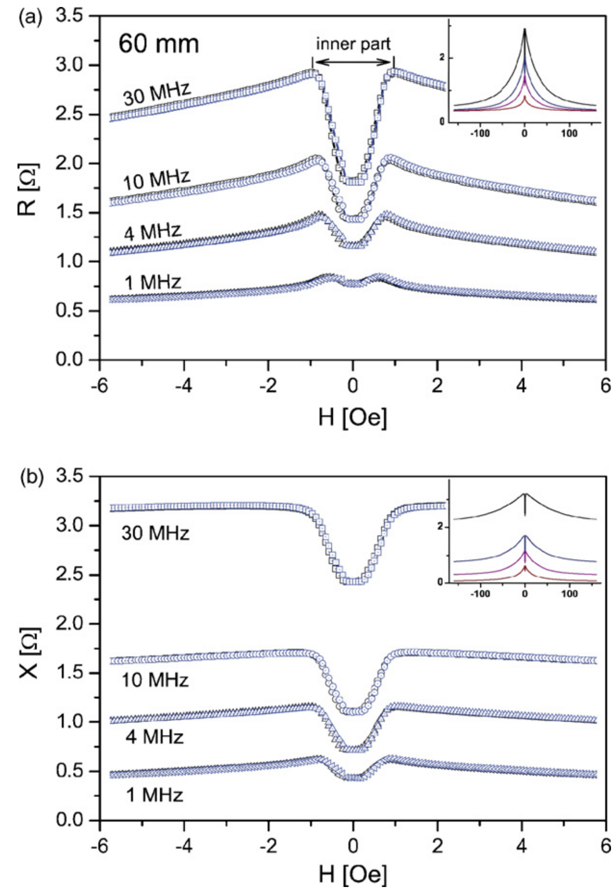

Fig. 2. Field dependence of the real (a) and imaginary (b) components of the impedance of L1-sample.

3. Results and discussion

3.1. Material characteristics

The dependencies of the real, *R*, and imaginary, *X*, components of the impedance on the external axial dc-field for the as-quenched sample (L1), are shown in Fig. 2a and b. A slight hysteresis is seen in these curves plotted with an increase and decrease of the magnetic field. In order to reduce an effect of the demagnetizing field, the measured sample was relatively long (much longer than the distance between the voltage contacts). The obtained two-peak characteristics were measured at various frequencies of the ac-current of the intensity of 10 mA (rms). This intensity was chosen to be small enough so that the influence of Joule heating could be neglected. It should be noticed that the characteristics measured using the current of 1 and 20 mA are almost identical, indicating that the dependence of the magnetoimpedance on current (in this range) is small. This suggests that in the case of the samples studied the voltage response is approximately linear within the whole range of applied currents and frequencies [16]. Therefore, the use of the impedance meter is justified; it can be expected that the voltage response is adequately represented by *R* and *X*. The observed large increase of the stable (field independent) contribution to the reactance *X* with frequency occurs because of the "external" (geometrical) inductance of the sample. This effect is eliminated if the measuring system is calibrated by subtraction of the impedance of magnetically saturated sample (which often takes place). However, this contribution should be taken into account, if the application is the primary goal of the investigations.

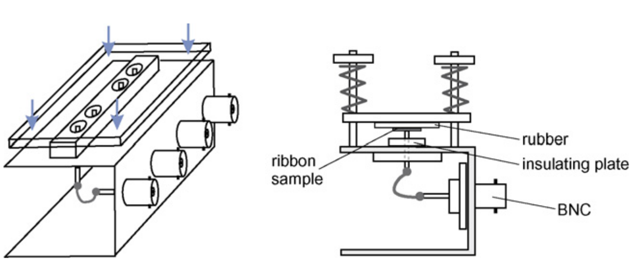

Fig. 1. The sample holder used for magnetoimpedance measurements.

The shape of the *Z*(*H*) characteristic depends strongly on magnetic anisotropy (type, distribution) and can be optimized by a thermal treatment of the material. Annealing can be performed in order to either remove the intrinsic stresses (stress-relaxing annealing) or induce intentionally magnetic anisotropy while annealing under mechanical stress or in a presence of magnetic field [12]. In this work the results of relaxing annealings are presented.

The ribbon used exhibits relatively low Curie temperature; therefore, a creation of magnetic anisotropy by field annealing is rather a difficult task [17,18]. The results of the stress annealing