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Journal of Magnetism and Magnetic Materials 302 (2006) 223–227
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Giant magnetoimpedance in amorphous $(Co_{0.93}Fe_{0.7})_{63}Ni_{10}Si_{11}B_{16}$ glass-coated microwire

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Received 8 August 2005
Available online 30 September 2005

Abstract

Giant magnetoimpedance (GMI) effect has been measured in a glass-coated amorphous $(Co_{0.93}Fe_{0.7})_{63}Ni_{10}Si_{11}B_{16}$ microwire as a function of DC magnetic field and up to the frequency of 11 MHz. The sample shows single peak GMI characteristics within the whole range of frequency. The domain structure of the above sample has been changed by applying tensile stresses up to 603 MPa and current annealing with a DC current of 50 mA for various time durations, and the corresponding effect on GMI has been studied in detail. A maximum change of 8.85% in MI of the as-quenched sample has been observed around a frequency of 5.05 MHz. Application of an external tensile stress reduces the GMI value by increasing the inner core domain, whereas heat treatment of the sample enhances the same. The square-shaped magnetic hysteresis loop of the as-quenched sample helps us understanding the MI results.

Keywords: Giant magnetoimpedance; Amorphous microwire; Magnetic properties; Stress; Annealing

1. Introduction

Giant magnetoimpedance (GMI), which is the large change in impedance (MI) with DC magnetic field, H_{DC} in low magnetostrictive amorphous magnetic materials has recently become a topic of growing interest because of its possibility to be used in many applications such as magnetic recording heads and micromagnetic sensors [1–4]. GMI effect varies with varying frequencies of the exciting AC current [5]. At low frequency (~kHz) the field dependence of the GMI is attributed to the inductive term of the impedance $Z = R + j\omega L$ which is proportional to the differential circumferential permeability [2]. At sufficiently high frequency (~MHz), the effect originates from the dependence of the skin depth, δ, upon the transverse magnetic permeability, μ_φ, of the materials. At a particular frequency, the applied DC magnetic field changes μ_φ and, hence, the penetration depth, which in turn changes the MI until the value of δ reaches the radius of the material [6].

Due to the absence of crystal structure, the main source of anisotropy in amorphous magnetic materials is the magnetoelastic anisotropy [7]. During the preparation of wires and microwires by the method of rapid quenching, a stress-induced anisotropy is developed within these samples, which governs the domain structure in these materials [8]. These wire-shaped samples consist of an inner core (IC) domain having a magnetization direction closely parallel to the wire axis and a multidomain outer shell (OS) with transversely oriented magnetization (radial and circular for positive and negative magnetostrictive samples, respectively) [9]. MI contributions from the IC and OS are different [10]. The transverse circular magnetization process in IC and OS is mainly by rotation and domain wall displacement, respectively. As the rotational relaxation is a faster process than the domain wall displacement relaxation, MI of OS is reduced much more compared to that of the IC at higher frequencies. The peak value of MI due to OS is obtained for an axial applied field equaling the anisotropy field of that region which is much higher than the switching field of the IC, where the peak in MI of the IC is observed. Therefore, the field sensitivity of MI of IC is

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0304-8853/$ - see front matter
doi:10.1016/j.jmmm.2005.09.009

also higher than that of OS, which is much desirable for various applications.

The fractional volume of IC or OS depends on the shape anisotropy, as well as on internal and external stresses. We have reported here the MI behavior of amorphous glass-coated $(Co_{0.93}Fe_{0.7})_{63}Ni_{10}Si_{11}B_{16}$ microwire, mainly consisting of the inner core domain, as it exhibits only square-shaped hysteresis loop when magnetized axially. The MI of the microwire is affected significantly due to the change in volumes of the two domain regions by applying tensile stress and current annealing. The sample shows single-peak MI behavior within the measured range of frequency.

2. Experimental

Glass-coated amorphous microwires of nominal composition $(Co_{0.93}Fe_{0.7})_{63}Ni_{10}Si_{11}B_{16}$ of length 12 cm and metallic diameter ~14 μm (diameter including the glass coating ~19 μm) were used for the experiment. The impedance of the sample was measured by a spectrum/network analyzer (Hewlett Packard, 3589A, 10 Hz–150 MHz) which was connected to a computer data acquisition system [9,10]. The frequency of the AC was varied from 0.6 to 11 MHz. A DC magnetic field parallel to the axis of the sample was applied by a pair of Helmholtz coils. The axis of the Helmholtz coil as well as that of the sample was kept perpendicular to the Earth's magnetic field to minimize its effect on the sample. To study the effect of stress on GMI, tensile stresses, σ, up to 603 MPa was applied along the axis of the sample. For investigating the effect of heat treatment in the presence of a circular magnetic field, a DC current with amplitude, $I_{an} = 50$ mA has been passed through the samples for various time duration, T_{an}, starting from 5 to 35 min. The percentage change of magnetoimpedance with applied magnetic field is described by the relation

$$\frac{\Delta Z}{Z}(\%) = 100\left[\frac{Z(H) - Z(H_{max})}{Z(H_{max})}\right], \quad (1)$$

where $H_{max} = 120$ Oe, the maximum applied magnetic field.

3. Results and discussions

Fig. 1 shows the field dependence of MI of glass-coated amorphous $(Co_{0.93}Fe_{0.7})_{63}Ni_{10}Si_{11}B_{16}$ microwire at a frequency of 5.05 MHz in the presence of a tensile stress, σ, of (a) 0 MPa, (b) 603 MPa, and (c) after current annealing with $I_{an} = 50$ mA for $T_{an} = 25$ min. The sample under the above conditions show single-peak MI profile with the peak value $[\Delta Z/Z(\%)]_{max}$ at H_{DC}~0. The value of $[\Delta Z/Z(\%)]_{max}$ decreases from 8.85% in the absence of any stress to 3.92% when $\sigma = 603$ MPa is applied and increases to 18.74% on current annealing, as mentioned above. Fig. 2 shows the variation of $\Delta Z/Z(\%)$ with H_{DC} of the above microwire at a frequency of 11 MHz in the presence of a tensile stress of (a) 0 MPa, (b) 603 MPa, and (c) after

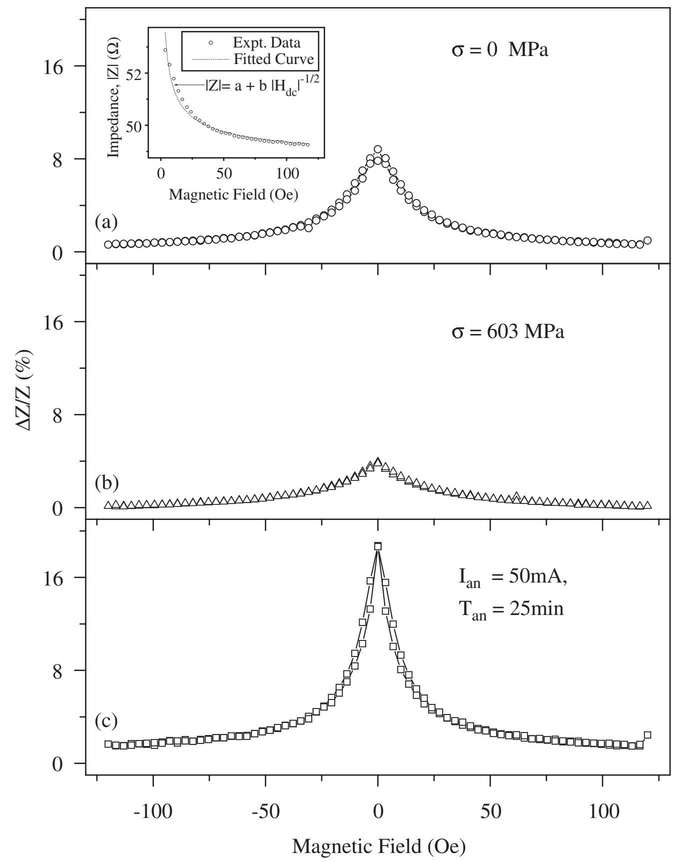

Fig. 1. Variation of $\Delta Z/Z(\%)$ with H_{DC} of glass-coated amorphous $(Co_{0.93}Fe_{0.7})_{63}Ni_{10}Si_{11}B_{16}$ microwire at a frequency of 5.05 MHz with (a) $\sigma = 0$ MPa, (b) $\sigma = 603$ MPa, and (c) after current annealing with $I_{an} = 50$ mA, $T_{an} = 25$ min. Inset shows the fitting of $Z| = a + b|H_{DC}|^{-1/2}$ with $a = 48.42$, $b = 9.49$ to the impedance, $|Z|$ versus magnetic field experimental data taken at a frequency of 5.05 MHz in the absence of any stress.

current annealing with $I_{an} = 50$ mA for $T_{an} = 25$ min . The value of $[\Delta Z/Z(\%)]_{max}$ decreases from 4.0% in the absence of any stress to 2.76% when $\sigma = 603$ MPa, whereas it increases to 5.88% on current annealing.

The frequency dependence of maximum value of $\Delta Z/Z(\%)$, i.e. $[\Delta Z/Z(\%)]_{max}$, is shown in Fig. 3 in the presence of different tensile stresses. At low frequencies, i.e. below 2 MHz, the change in $\Delta Z/Z(\%)$ is small and around 5.05 MHz, the field response of GMI is maximum. In this frequency region, the effect of applied stress is also large, i.e. $[\Delta Z/Z(\%)]_{max}$ decreases significantly with the increase in stress. Fig. 4 shows the frequency dependence of $[\Delta Z/Z(\%)]_{max}$ of the annealed sample on annealing with $I_{an} = 50$ mA for various durations. The GMI value increases up to $T_{an} = 25$ min. The best response is obtained again around a frequency of 5.05 MHz, with $[\Delta Z/Z(\%)]_{max}$~18.74% when the sample is annealed for 25 min and the field sensitivity of GMI, $(1/\Delta H)(\Delta Z/Z)$ is 93%/Oe around an applied magnetic field of 5 Oe. The GMI value deteriorates on further annealing, and $[\Delta Z/Z(\%)]_{max}$ decreases to ~13.27% when $T_{an} = 35$ min.