INFLUENCE OF HELICAL ANISOTROPY ON GMI EFFECT IN CO-BASED AMORPHOUS FERROMAGNETIC MICROWIRES

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1. Introduction

Glass-coated ferromagnetic amorphous thin wires (microwires) of a diameter of 10 μm are prepared by a drawing and quenching method [1]. During this preparation procedure the radial, axial and torsion mechanical stresses are induced in the microwires. The preferential orientation of the spontaneous magnetization (anisotropy) in the microwire is given by the magnetostriction. We observe a relatively small negative magnetostriction in cobalt based microwires which results in the creation of a wide almost circularly magnetized sheath and a narrow axially magnetized core in the ferromagnetic metallic central part [2]. Different mechanical properties of the ferromagnetic metallic central part and of the glass cover of the microwire are responsible for slight deviation of spontaneous magnetization from circular direction in the sheath of the microwire (helical anisotropy). The giant magnetoimpedance (GMI) effect, which is mainly a surface effect, is very sensitive to the rotation of magnetization in the sheath of the microwire [3]. For this reason a measurement of GMI effect is often used to determine the surface magnetic properties of cobalt based microwires.

2. Theoretical background

For a circular wire it is convenient to use cylindrical coordinates. Helical anisotropy given by a preferable orientation (easy axis) of the spontaneous magnetization of the microwire can be then expressed as $\boldsymbol{M} = (M_r, M_\phi, M_z) = (0, M_s \cos\alpha, M_s \sin\alpha)$ at zero external magnetic field, where M_s is the saturation magnetization, α is the angle of deviation of the easy axis of magnetization from the circular direction of the microwire. The value of α determines the shape of the magnetization curve of the microwire during its magnetization

along the longitudinal wire z-axis [4]. Fig. 1 (right) illustrates the magnetization curve for α=0 (hard axis of magnetization is the longitudinal wire z-axis). The classical quasistatic theory of the skin effect gives us the expression for the impedance of a cylindrical conductor with radius a :

$$Z \approx \frac{Z}{R_{dc}} = \frac{ka}{2}\frac{\mathrm{J}_0(ka)}{\mathrm{J}_1(ka)}, \text{ where } k = \frac{1+\mathrm{i}}{\delta}, \delta = \sqrt{\frac{2\rho}{\omega\mu_\phi}} \tag{1}$$

J_i denotes the Bessel function of the i-th order, ρ is resistivity, ω is angular frequency and μ_ϕ is circular permeability [3]. The quasistatic model based on the minimization of the free energy of the domain structure was developed [5]. This model is successful in explaining the existence of peaks in the GMI dependence in Fig. 1 (left) which corresponds to the calculated circular permeability dependence $\mu_\phi(H)$ if only a reversible magnetization rotation is present (Fig. 1 (right)).

3. Experimental results

The GMI ratio is usually defined as $\Delta Z/Z=\{|Z(H)|-|Z(H_{max})|\}/|Z(H_{max})|$, where $|Z|$ is the impedance modulus and H_{max} is the maximum of the static measuring field H at which the sample is considered to be magnetically saturated. In the presented experiments the GMI ratio at the frequency of 1 MHz was measured at different amplitudes i_{ac} of the harmonic current flowing through the microwire $Co_{70.5}Fe_{4.5}Si_{15}B_{10}$ [6].

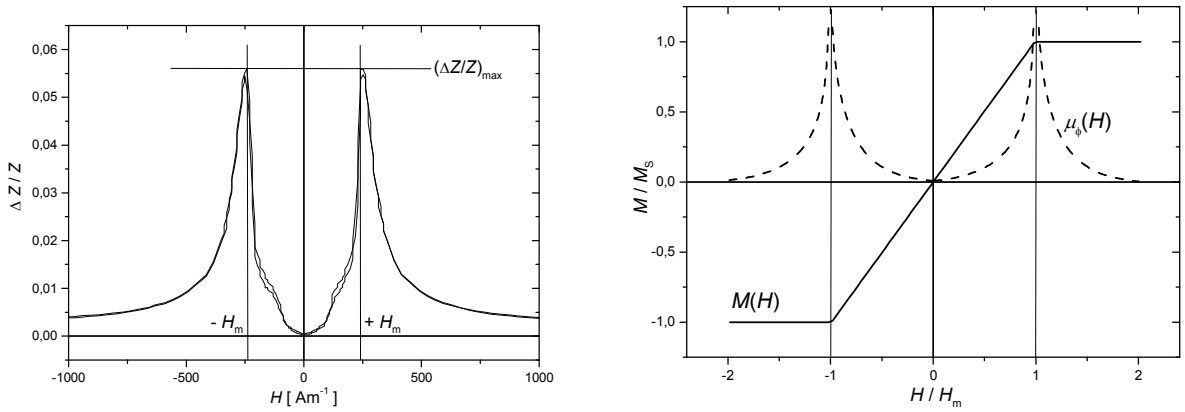

Fig.1: *GMI dependence in $Co_{70.5}Fe_{4.5}Si_{15}B_{10}$ microwire measured at the frequency 1 MHz and at the amplitude i_{ac}=1 mA (left), Magnetization curve M(H) in case of uniaxial anisotropy with α=0 and circular permeability μ_ϕ(H) (right).*

From the GMI ratio dependences which exhibit a double–peak behaviour in Fig. 1 (left) the maximum value of GMI ratio $(\Delta Z/Z)_{max}$ and its positions $-H_m$ and $+H_m$ were plotted as functions of amplitudes i_{ac} in Fig. 2.

4. Discussion

The measured GMI dependence in Fig 1 (left) displays the similar behaviour with circular permeability dependence $\mu_\phi(H)$ illustrated in Fig. 1 (right). This correlation results directly from Eq. (1). Possible explanation is that for very low amplitudes i_{ac} (or circular field $H_\phi = i_{ac} / 2\pi a$) a reversible magnetization rotation only takes place in the sheath of the microwire if it is taken into account that a reversible domain wall movement at the frequency of 1 MHz is negligible due to a strong damping process. The obtained $(\Delta Z/Z)_{max}$ dependence exhibits maximum at amplitude i_{ac} = 1 mA (or H_ϕ= 22.7 Am^{-1}) which indicates the limit for the reversible magnetization rotation. Onset of an irreversible magnetization rotational process causes the decrease of $(\Delta Z/Z)_{max}$ in Fig 2 (left) at amplitudes i_{ac} > 1 mA (or H_ϕ>22.7 Am^{-1}). We also observe a hysteretic behaviour in the measured GMI dependences [6]. The irreversible rotation of magnetization can be explained by the helical anisotropy ($\alpha \neq 0$) where the rotational jumps of magnetization into the opposite direction occur. The magnitude of rotational jumps of magnetization depends on the angle α as well as on the amplitude i_{ac}.

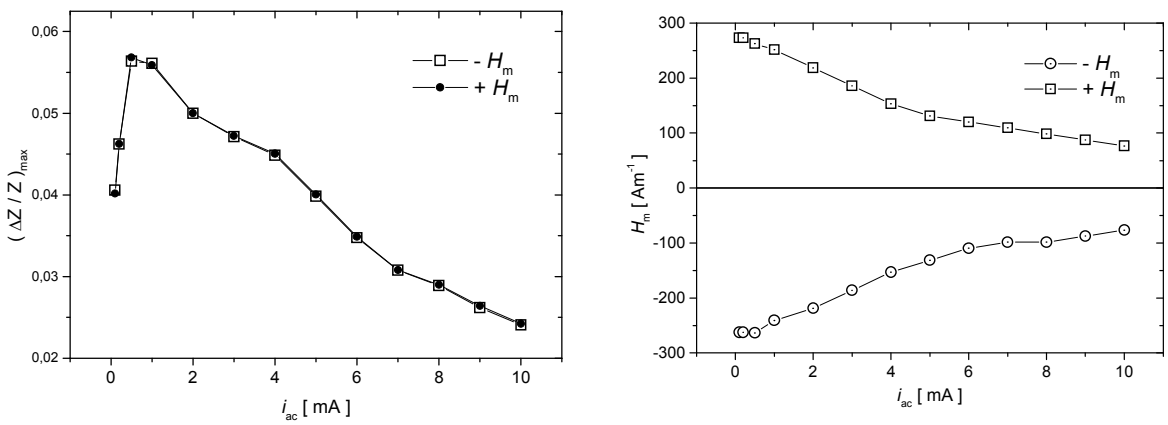

Fig.2: *Maximum value of GMI ratio $(\Delta Z/Z)_{max}$ (left) and its positions $-H_m$ and $+H_m$ (right) as function of amplitude i_{ac} determined from GMI dependences in $Co_{70.5}Fe_{4.5}Si_{15}B_{10}$ microwire measured at the frequency 1 MHz, as a Fig. 1.*

5. Conclusion

The maximum GMI ratio $(\Delta Z/Z)_{max}$ dependence on the amplitude i_{ac} (or circular field $H_\phi = i_{ac} / 2\pi a$) was analysed by means of the helical anisotropy ($\alpha \neq 0$). Firstly, if the reversible magnetization rotation occurs, then the maximum GMI ratio $(\Delta Z/Z)_{max}$ increases with amplitude $i_{ac} \leq 1$ mA (or circular field $H_\phi \leq 22.7$ Am^{-1}). Secondly, if the irreversible rotation of magnetization starts at $i_{ac} > 1$ mA (or circular field $H_\phi > 22.7$ Am^{-1}), then the hysteretic behaviour is observed in the measured GMI dependences [6]. These phenomena are here explained by means of the helical anisotropy ($\alpha \neq 0$) existing in the glass-coated ferromagnetic amorphous CoFeSiB microwire.

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