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STRESS AND TEMPERATURE EFFECT ON THE FMR RESPONSE OF NEARLY ZERO MAGNETOSTRICTIVE AMORPHOUS MICROWIRES

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Results on the ferromagnetic resonance (FMR) investigation of the effect of applied tensile stresses and different temperatures during measurements on the surface magnetic anisotropy of $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous glass-covered microwires are reported. Axial stresses determine a decrease of the resonance field and an increase of the absorption intensity that correspond to the resonance peak, indicating a reinforcement of the circumferential magnetoelastic anisotropy from the microwire's surface region. An increase of the temperature during measurements up to 160 °C leads to a significant increase of the resonance field that corresponds to a decrease of the circumferential magnetoelastic anisotropy.

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1. Introduction

Ferromagnetic amorphous glass-covered microwires consist of a metallic core with diameters ranging from several micrometers to 30 μm covered by a glass insulator with a thickness of several micrometers up to 25 μm. Such microwires display remarkable soft magnetic properties that make them successful candidates in sensor devices [1]. They are prepared from magnetostrictive alloys (e.g. $Fe_{77.5}Si_{7.5}B_{15}$ with $\lambda_S = 25 \times 10^{-6}$, $Co_{80}Si_{10}B_{10}$ with $\lambda_S = -4 \times 10^{-6}$, and $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ with $\lambda_S = -1 \times 10^{-7}$) in a one step process called glass-coated melt spinning. The high quenching rates involved in this process along with the presence of the glass coating are responsible for large internal stresses induced during preparation. The magnetoelastic anisotropy that arises from the coupling between internal stresses and magnetostriction determines the magnetic behavior of these materials. Magnetostriction determines an increased sensitivity of their magnetic characteristics to applied mechanical stresses. Both magnetostriction and internal stresses change sensitively with temperature, and thus, the magnetoelastic anisotropy is expected to depend on the temperature used during measurements.

Ferromagnetic resonance (FMR) has been recently used to study the low field magnetization processes in amorphous glass-covered microwires with positive, negative, and nearly zero magnetostriction [2], the magnetic anisotropy distribution within positive magnetostrictive amorphous glass-covered microwires [3], and the evolution of the magnetic properties of FINEMET glass-covered microwires during nanocrystalline phase formation [4].

The aim of this paper is to report results on the changes that occur in the surface magnetic anisotropy of $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous glass-covered microwires subjected to applied tensile stress or different temperatures during measurements. CoFeSiB amorphous microwires with nearly zero magnetostriction are potential candidates in magnetic sensors based on the giant magneto-impedance effect. Therefore, it is important to know the effect of both applied stresses and temperature on their magnetic characteristics, especially as regards their magnetoelastic anisotropy

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from the surface region, which is involved in the high frequency magnetization process. FMR is the most convenient method to investigate the surface anisotropy changes of such microwires with applied stress and temperature.

2. Experimental details

$Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous glass-covered wires with typical dimensions - diameter of the metallic core of 26 μm and the glass cover thickness of 4.5 μm have been prepared by glass-coated melt spinning at the National Institute of R&D for Technical Physics Iaşi. The investigated samples were cut to 10 mm long pieces.

Microwave absorption FMR spectra of samples subjected to axial tensile stresses of different values up to 1.032 GPa were determined in a parallel configuration - dc magnetic field parallel to the wire axis - with an X-band spectrometer, at a frequency of the microwave field of 8.5 GHz. The employed power of the microwave field was 150 μW. Using the same parameters in the FMR experiment, we subsequently monitored the changes in the surface anisotropy determined by different temperatures during measurements, for temperatures up to 160°C.

3. Results and discussion

Fig. 1 shows the FMR spectra of the sample subjected to zero applied stress, and to the maximum applied stress (1.032 GPa), respectively. One observes that the resonance peak of the sample subjected to the maximum stress is sharper and slightly shifted to the left, towards lower field values as compared to the one subjected to zero stress. On the other hand, the absorption intensity of the sample subjected to 1.032 GPa is larger as compared to the as-cast one.

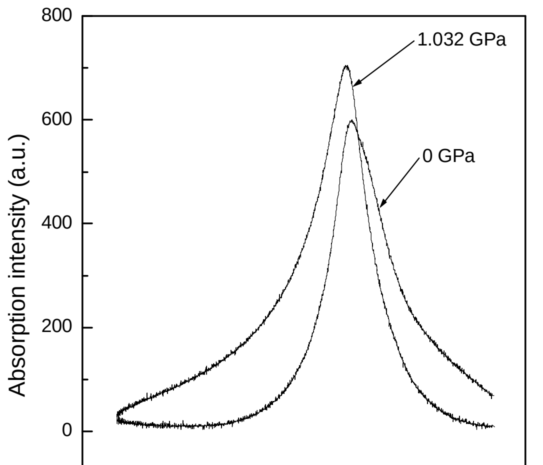

Fig. 1. FMR spectra of a $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous glass-covered microwire with the metallic core diameter of 26 μm and the glass coating thickness of 4.5 μm obtained with no applied stress and with an applied stress of 1.032 GPa, respectively.

These observations are consistent with earlier results on the magnetoelastic anisotropy of amorphous glass-covered wires with this composition, obtained indirectly by both circumferential BH loop measurements and internal stress calculations [5]. According to these previous results, CoFeSiB amorphous glass-covered wires with nearly zero but still negative magnetostriction display a region with circumferential easy axis near the surface. The circumferential anisotropy is of magnetoelastic origin and results from the coupling between the small negative magnetostriction and the large circumferential compressive (negative) internal stresses ($K_\theta \propto \lambda\sigma_{\theta\theta}$).

Thus, one can state that the resonance peak is caused by the response of a part of the region with circumferential anisotropy. The volume fraction of the responding part is determined by the actual value of the magnetic penetration depth, which is quite difficult to estimate exactly because the magnetic permeability drops at these high frequencies.

The decrease of the resonance field is consistent with a reinforcement of the circumferential anisotropy as a consequence of the transverse Poisson contraction of the wire that accompanies axial stretching. Thus, the compressive circumferential stress from the wire surface increases, and K_θ increases accordingly. The increment of the absorption intensity, showing the sharpest absorption line under maximum applied tensile stress, sustains the strengthening of circumferential anisotropy.

Besides the differences in the characteristics of the resonance peak, one can easily observe a qualitative alteration of the spectrum determined by the applied stress. Thus, the spectrum of the sample subjected to the maximum tensile stress shows an increased level of absorption before the resonance peak itself (at lower field values), while the sample subjected to zero stress displays an increased level of absorption after the resonance peak. These results are consistent with changes in the anisotropy distribution associated to the responding region. Such changes appear due to quantitative modifications in the intrinsic internal stress distribution determined by applied tensile stresses. However, since the half-width of the spectra does not change significantly with applied stress, one can state that the degree in which local anisotropies are spread in this region is not altered qualitatively by external stresses. The absorption occurring after resonance for the unstressed sample illustrates that there is a significant number of magnetic moments characterized by lower values of anisotropy field as compared to the maximum value, usually associated to the region from the immediate vicinity of the wire surface. On the other hand, the absorption occurring just before resonance in the sample subjected to the maximum tensile stress shows that the anisotropy field that characterizes most of the magnetic moments from the responding region has significantly increased due to applied stress.

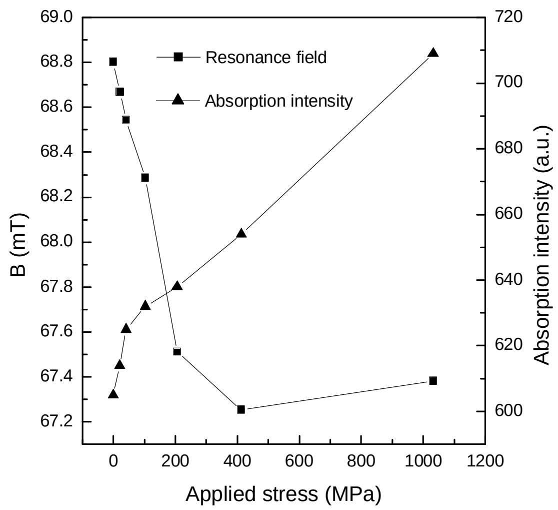

Fig. 2. Stress dependence of the resonance field and absorption intensity corresponding to the resonance peaks of a $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous glass-covered microwire with the metallic core diameter of 26 μm and the glass coating thickness of 4.5 μm, subjected to applied tensile stresses of different values.

Fig. 2 illustrates the stress dependence of the resonance field and absorption intensity. One observes that the resonance field decreases with applied stress, following an exponential decay-like equation. Only between the applied stress values of 413 MPa and 1.032 GPa one can observe a very small increment of the resonance field, which can be attributed to changes of the internal stress tensor components by the applied stress, in the sense that the dominant component that determines the circumferential anisotropy in the inner part of the responding region becomes the positive axial stress instead of the negative circumferential one.

The absorption intensity increases monotonically with applied stress. The microwave field tends to push the magnetic moments out of the equilibrium position, which is the axial direction, towards the transverse direction which is favored by the circumferential anisotropy. Consequently, when the circumferential anisotropy increases as a result of applied tensile stress, the FMR response of the magnetic moments is sharper, i.e. the energy absorbed at resonance is larger due to the increased tendency of the moments to lie along the circumferential easy axis.

Fig. 3 shows the changes of the FMR spectrum with the temperature during measurements, while Fig. 4 illustrates the temperature dependence of the resonance field. One observes that the resonance field increases monotonically with temperature, reaching a maximum value of 78.6 mT at a temperature of 156 °C during measurements. This value represents an increase of 15% as compared to the resonance field measured at room temperature.

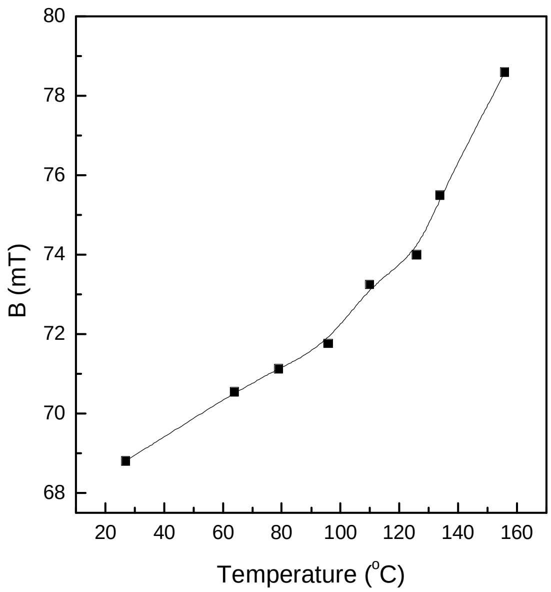

Fig. 3. FMR spectra with the temperature during measurements for a $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous glass-covered microwire with the metallic core diameter of 26 μm and the glass coating thickness of 4.5 μm.

This behaviour of the resonance field can be explained by taking into account the decrease of the circumferential surface magnetic anisotropy that takes place mainly due to the stress relief determined by temperature. Another contribution to this effect is given by the amorphous state of the microwires, which most probably suffers metastable relaxations as the temperature increases.

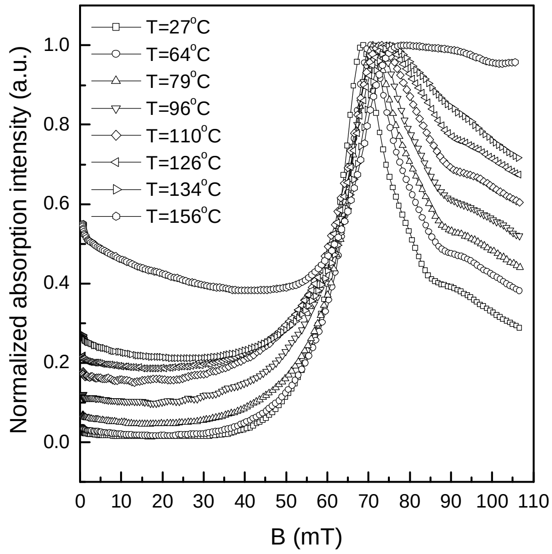

Fig. 4. Temperature dependence of the resonance field for a $Co_{68.25}Fe_{4.5}Si_{12.25}B_{15}$ amorphous glass-covered microwire with the metallic core diameter of 26 μm and the glass coating thickness of 4.5 μm.

4. Conclusions

The circumferential magnetoelastic anisotropy of CoFeSiB amorphous glass-covered microwires is strengthened by axially applied stresses, fact demonstrated by the decrease of the resonance field and by the increment of the absorption intensity that correspond to the obtained resonance peaks.

On the other hand, temperature has a stronger effect on the surface circumferential magnetoelastic anisotropy of these materials, due to both stress relief and amorphous state, which is expected to suffer metastable relaxation processes.

The results are important for sensor application of these materials, as well as from the point of view of the thermal stability of devices based on such microwires.

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