INFLUENCE OF THE DOMAIN STRUCTURE ON THE IMPEDANCE OF FERROMAGNETIC WIRE

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1. Introduction

The magneto-impedance effect has been intensively studied during the last two decades. The great sensitivity of the effect to very low values of external magnetic field makes it very promising for technological application [1].

The magneto-impedance effect is defined as a relative change in the real and imaginary components of impedance due to an external magnetic field. The interpretation of this effect is based on the skin effect and for this reason the main parameter for its characterization is so-called skin depth δ. This parameter specifies the thickness of the region beneath the surface of the conductor through which the ac current flows. This means that, if high frequency current flows through the material, current density is not homogeneously distributed through its cross section, but current flows through a certain layer beneath the surface of the conductor [2].

Skin depth δ decreases with increasing frequency of ac current f, circumferential magnetic permeability μ_φ and electrical conductivity of the material σ [3].

2. Experimental

Measurements were carried out on low magnetostrictive amorphous ferromagnetic $Co_{68.2}Fe_{3.4}Si_{12.5}B_{15}$ wire with nominal diameter of 125 μm prepared by the in-rotating-water quenching technique. Total length of the sample was 5.2 cm. Two thin copper wires were attached to the wire with silver paint at a distance 2.7 cm around the centre of the sample. Dc electrical resistance R_{dc} between these contacts was 3.1 Ω. A detailed description of the experimental set-up can be found in [4].

The sample was placed in a holder which enabled torsion and tensile stresses to be applied simultaneously. Circular anisotropy could be increased by applying tensile stress. Dominant helical anisotropy was minimized by applying torsion stress.

The axial hysteresis loops presented in this paper were not measured continuously but point by point. A two-step procedure was used for measurement of a single point on these loops. In the first step the magnetic history of the sample was defined. For instance, if a single point on the ascending branch of the loop was measured, the axial field was changed from its positive maximum value to the negative one and then this field was changed to the measuring value. In the second step magnetic flux or impedance corresponding to the magnetic state at the end of the first step was measured. The advantage of this way of measurement is the possibility of changing procedures in the first step and thus also of modifying the magnetic history.

3. Result and discussion

Measurements of axial loops of circular magnetic flux (Φ_φ vs. H see Fig. 1) were used to find the state with minimum helical anisotropy. These loops were measured at the tensile stress of 400 MPa and results are shown in Fig. 1. The state in which circular magnetic flux on the Φ_φ vs. H loops had minimum value was obtained for torsion of about 1.57 rad/m. The influence of the dc current (circular magnetic field) pulse on the magnetic state is also shown in Fig. 1. At the end of the first step of the measuring procedure of each point a rectangular current pulse (about 1 second long) was sent through the wire. It is clear that the applied current pulse causes significant irreversible changes in the magnetic state of the sample.

Similar procedures were used for measurements of the magneto-impedance loops shown in Fig. 2. Measured quantities can be defined by description of the measurement of a single point on the ascending branch of the loop. This started at maximum field $-H_{max}$, where impedance Z_{max} was measured. Then the field was changed to measuring value H and impedance Z_1 was measured. In the next step the current pulse was sent through the wire and impedance Z_2 was measured. The whole procedure was completed with a change of the axial field to the value $+H_{max}$. The change in impedance with respect to the maximum field before applying the dc current pulse is $\Delta Z_1 = Z_1 - Z_{max}$. The change in impedance with respect to the maximum field after applying the current pulse is $\Delta Z_2 = Z_2 - Z_{max}$. Low-field loops of magneto-impedance ratio $\Delta Z/R_{dc}$ for two frequencies and $H_{max} = 860$ A/m are plotted in Fig. 2.

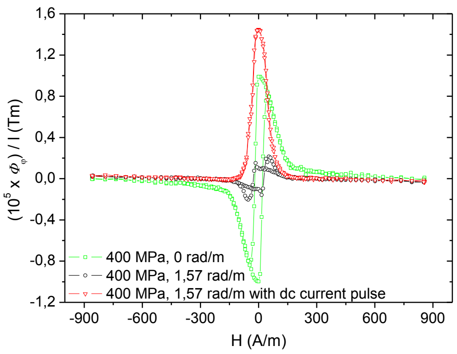

Fig. 1: *The influence of torsion and dc current pulse of magnitude 3mA on axial hysteresis loops of circular magnetic flux.*

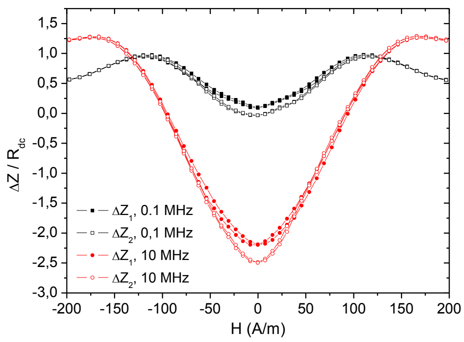

Fig. 2: *Magneto-impedance loops for two frequencies without dc current pulse (ΔZ_1) and after dc current pulse of magnitude 3 mA (ΔZ_2). Amplitude of ac current $I_m = 0.14$ mA.*

As expected the magneto-impedance curve have a typical two-peak shape. The dc current pulse causes an irreversible decrease in impedance in the fields close to zero.

The influence of magnitude of the current pulse on the magnetic state in a zero axial field was the subject of further experiments, the results of which are presented in Figs. 3, 4.

Magneto-impedance curves as a function of magnitude of current pulse (circular field H_φ at the wire surface) for different frequencies are shown in Fig. 3. Here the magneto-impedance ratio is defined as $\Delta Z_3/R_{dc}$, where $\Delta Z_3 = Z_2 - Z_{2max}$ and Z_{2max} is the wire impedance after application of a current pulse of maximum amplitude (4.8 mA). The same dependence of circular magnetic flux is shown in Fig. 4. The magneto-impedance curves have the typical shape for all frequencies. In the low field region a characteristic plateau of almost constant impedance can be observed. At a circular field of about 1 A/m, rapid decrease in impedance starts and finally for a field higher than about 6 A/m the impedance becomes constant. Very similar behaviour can be observed in the curve of circular magnetic flux in Fig. 4. The same regions can also be identified on this curve. Interpretation of this behaviour is schematically shown in Fig. 5. Three possible magnetic states A, C, D after switching off the external fields (axial and circular) and the one state B for non-zero circular field are depicted in this figure. Reduction of dominant helical anisotropy can result in the creation of a relatively high number of regions with different local helical anisotropies. This distribution of helical anisotropy can result in a great number of circular domains in the axial remanent state (state A). The circular field created by the current pulse causes domain wall displacement (state B). Low magnitudes of circular field result in reversible displacement of domain walls, and this is why no changes in circular magnetic flux are observed. Domain structure returns to state A after the current pulse. Since there is no change in magnetic state no changes are observed in the magneto-impedance curve either. For a circular field higher than 1 A/m, domain wall displacements become irreversible and some of the walls even disappear (state C). These processes result in decrease in impedance. For circular fields higher than about 6 A/m, all walls disappear (state D) and no further changes are observed in both impedance and circular magnetization curves.

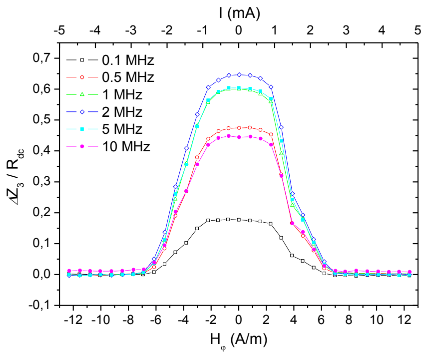

Fig. 3: *Impedance change versus magnitude of dc current (circular magnetic flux H_φ) pulse measured in zero axial field for different frequencies.*

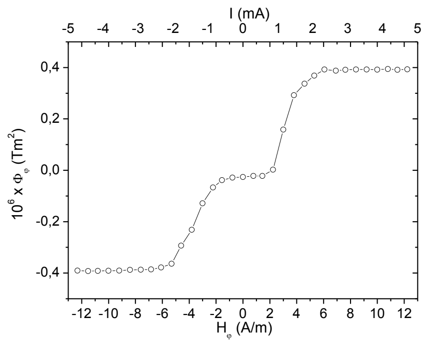

Fig. 4*: Circular magnetic flux versus magnitude of dc (circular magnetic flux H_φ) current pulse measured in zero axial field.*

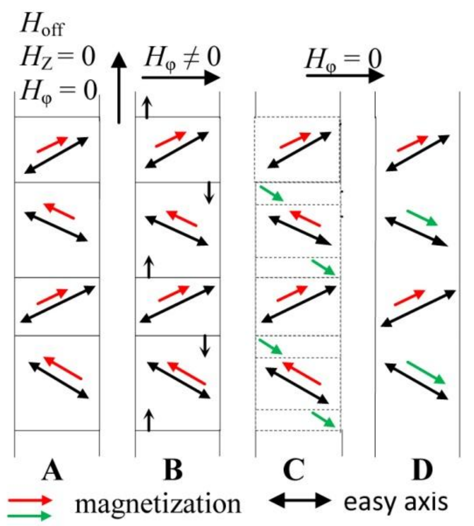

Fig. 5: *Domain structure changes caused by dc circular field pulse.*

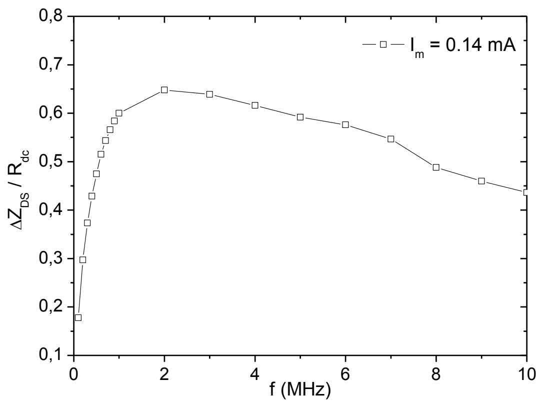

Fig. 6: *Frequency dependence of domain structure contribution to the impedance measured in zero axial field.*

Based on this interpretation the contribution of domain structure to the wire impedance can be determined from the magneto-impedance curve in Fig. 3. This contribution is given by the ratio $\Delta Z_{DS}/R_{dc} = (\Delta Z_2/R_{dc})_{H\varphi=0}$. Frequency dependence of the domain structure contribution $\Delta Z_{DS}/R_{dc}$ to the wire impedance is shown in Fig. 6. Rapid increase in domain structure impedance in the frequency range from 0.1 MHz to 2 MHz can be observed. The maximum is achieved at a frequency of about 2 MHz and above this frequency a slow decrease is observed. It is very probable that the shape of this dependence is predominantly determined by the frequency dependence of domain wall oscillations. Magnetization inhomogeneities close to the boundary between regions with different helical anisotropies can be a source of stray fields. The presence of domain structure can influence these stray fields (compare magnetic state A and D in Fig. 5) and this mechanism can also contribute to the measured value of $\Delta Z_{DS}/R_{dc}$.

4. Conclusion

Magneto-impedance of amorphous ferromagnetic $Co_{68.2}Fe_{3.4}Si_{12.5}B_{15}$ wire with small negative magnetostriction was experimentally studied. Experimental procedures which allowed us the measure the contribution of circumferential domain structure to wire impedance were proposed. It was shown that the frequency dependence of domain structure contribution to wire impedance reaches the maximum at a frequency of about 2 MHz. The magnitude of the domain structure contribution to the impedance at this frequency is about 65% of the dc resistivity of the wire.

Acknowledgement

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