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STUDY OF DOMAIN STRUCTURE BY MAGNETO-OPTICAL METHODS

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We have focused on study of domain structure of amorphous glass – coated microwires of composition $Fe_{77.5}Si_{7.5}B_{15}$ applying magneto – optical Kerr effect. Initially, an experimental setup including specimen holders was designed and built. Afterwards, the reversal of longitudinal and transversal component of surface magnetization was studied. A measurement consisted of two phases – firstly, the magnetization reversal in different places along the wire showed that surface magnetization is inclined from the axial direction. Secondly, by rotating the wire in an alternating magnetic field and using MOKE, it was found that magnetization is rotated out of the wire's axis by approximately 10°.

Keywords: magneto – optics, microwires, direction of magnetization

1 INTRODUCTION

Magneto-optical methods have become significant among experimental approaches to study of domain structure and magnetization processes in microwires [1]. They make it possible to detect very small variations in a magnetic state of micro and nanomaterials as well as variations happening over a very short period due to short relaxation time of photodetectors [2]. Magnetic structure and magnetization processes in surface region of microwires are particularly important in relation to GMI [3]. On the other hand, the speed of domain wall movement is important in light of application of microwires in new types of computer memories or domain wall logic devices [4].

Using different experimental layouts, it is possible to measure the surface magnetization reversal in all three space dimensions, the shape of domain wall propagating through microwire [5] or its velocity [1, 2, 6].

This work is devoted to construction of experimental setup for measuring magneto - optical Kerr effect and to studying the surface domain structure of microwire $Fe_{77.5}Si_{7.5}B_{15}$. We have found that the surface magnetization is tilted from the axial direction of the wire by approximately 10°.

2 THEORY

Domain structure and magnetization processes in glass – coated amorphous Fe – rich microwires are well known [7, 8, 9]. They consist of bistable axially magnetized inner core and the outer shell, where magnetization has in general different direction than in the core, characterised by helical anisotropy. On both ends of the microwire, closure domains appear, in order to minimize the stray field of the inner core (Fig. 1).

Generally, bistable behaviour remains also in the outer shell in microwires with positive magnetostriction, such as $Fe_{77.5}Si_{7.5}B_{15}$.

Magnetization process is characterized by single Large Barkhausen jump reversing the magnetization of the inner core of the wire. Axial domain interacts with the outer shell resulting in surface magnetization reversal [8].

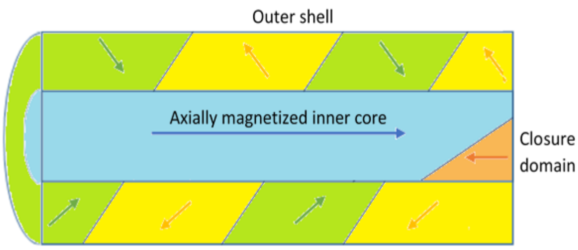

Fig. 1. Domain structure of microwire

3 EXPERIMENTAL

Specimen (a piece of microwire) was placed inside spatially homogenous, time – harmonic magnetic field that is generated in a small area in the middle of Helmholtz coils (HC). It had to be held on a platform made of non – magnetic, non – metallic material so it does not affect the space homogeneity of the surrounding field. Shape of the platform was designed in a way that it does not produce unwanted reflections. Only edges of the specimen were therefore fixed to the platform. All platforms were printed by 3D printer in a black colour in order to minimize theirs reflectivity (Fig. 2).

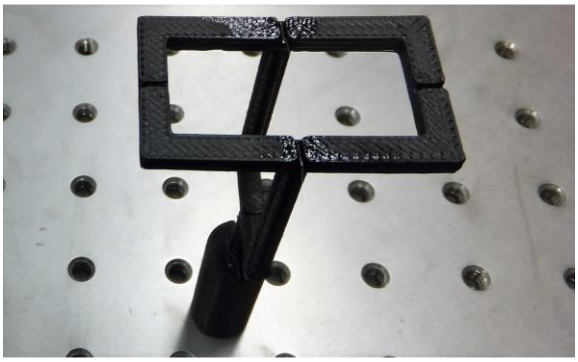

Fig. 2. Specimen holder

Platform was then fixed to a 3D printed tube connected to a goniometer and all of that was fixed to a stand placed outside of HC. The stand and the goniometer allow precise manipulation of the specimen (vertical and horizontal movement and rotation). However, it turned out

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that the axis of the goniometer was always inclined from the axis of the tube, hence whole specimen was translating in space during the rotation of goniometer (as opposed to a desire to do not change the position of a part of the microwire illuminated by laser beam). This problem was mostly solved by placing the rotating part to the end of the tube instead of the initial setup where the tube was inserted into goniometer. Simple two – piece goniometer with 10° step was designed and 3D printed for this purpose (Fig. 3).

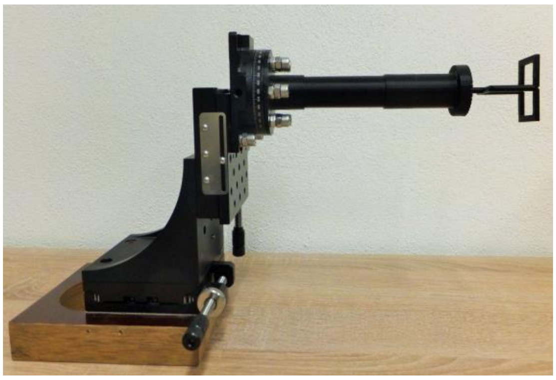

Fig. 3. Stand with two – piece goniometer mounted

Time dependence of the Kerr signal, which is proportional to the magnetization, was measured using Thorlabs Si Transimpedance Amplified Photodetector PDA100A. Thorlabs 5 mW laser generator produced laser beam with wavelength of 633 nm. Alternating magnetic field of HC was created by feeding them with harmonic AC signal with 40 Hz frequency and such amplitude, so that amplitude of the magnetic field in the middle of HC is approximately 1000 A/m. HC constant was 1560 m^{-1}.

Time dependence of the intensity of magnetic field in the middle of HC was measured, too. Both time dependences were displayed in real time on oscilloscope. Scheme of experimental setup is in the Fig. 4.

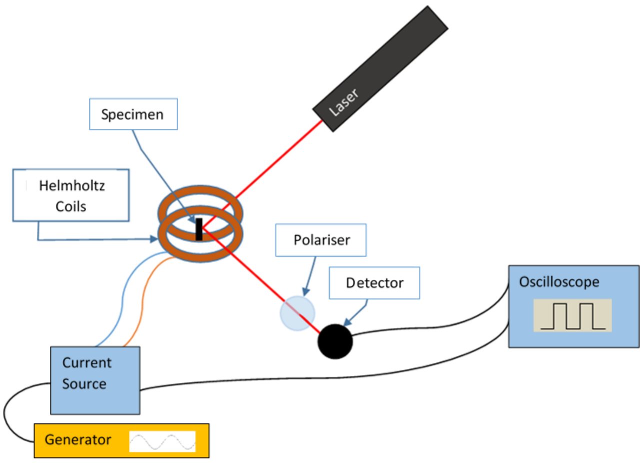

Fig. 4. Experimental setup

We used $Fe_{77.5}Si_{7.5}B_{15}$ amorphous glass – coated microwire placed in the middle of HC, with diameter of inner core 15 µm and 7.5 µm thick glass – coating. Length of the specimen was 2 cm. Microwire was oriented along the axis of HC and moved in the same direction, so that the area illuminated by laser beam and the angle of incidence are constant. Magnetization reversal for both transversal and longitudinal magnetization was measured on 14 different places (Fig. 5). They were by turns measured with the same detector. In case we wanted to measure reversal of longitudinal magnetization, polarizer crossed with linearly polarized light of the laser beam was placed in front of the detector. For the sake of completeness polar magnetization reversal was measured, too. However, no change of magnetization was visible in the signal. Based on that, one can assume that magnetization vector rotates in the plane of surface.

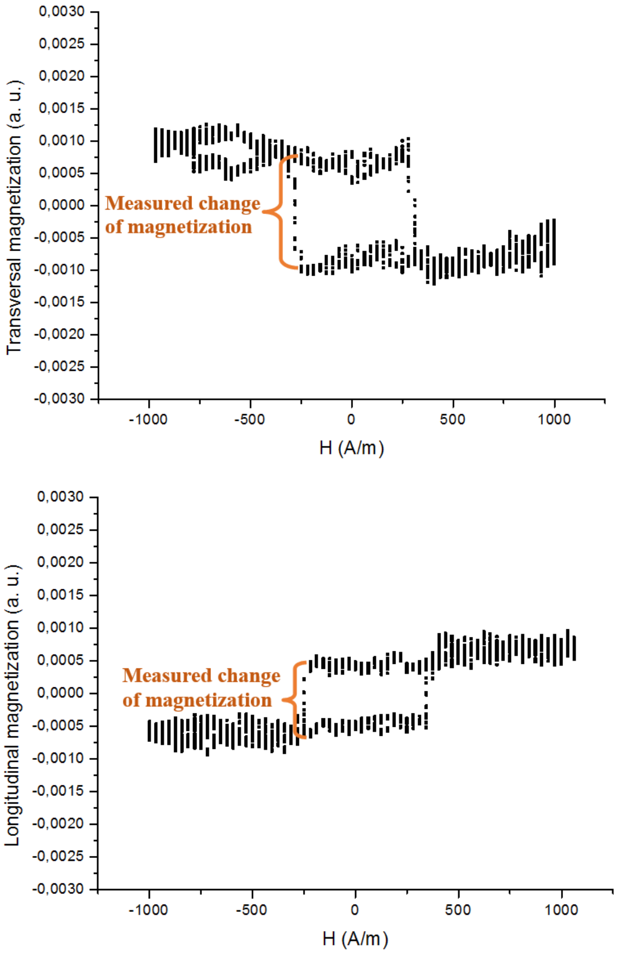

Fig. 5. Hysteresis loops measured by transversal and longitudinal MOKE show sharp change of magnetization due to Large Barkhausen jump.

4 RESULTS AND DISCUSSION

Important thing to notice is that with magnetic field applied along the microwire, the variation in longitudinal as well as transversal magnetization was always nonzero. Spontaneous magnetization must be thereby tilted from the axial direction.

Based on this assumption, longitudinal MOKE gives information about the variation of that component of magnetization, which lies in the plane of incidence and plane of the surface. Transversal MOKE gives information about the variation of component of magnetization, which lies in the plane of surface and is perpendicular to the plane of incidence. The change of longitudinal magnetization should consequently be maximal if the microwire is tilted (perpendicularly to the plane of incidence) by such an angle that spontaneous magnetization in the surface lies in the plane of incidence. Tilting angle would be –α where α is the angle between spontaneous magnetization and the axis of microwire. Hence, the angle by which magnetization is tilted from the axial direction can be estimated this way. Complementary result would implicate minimal change in transversal magnetization. Fig. 6 describes the situation for microwire in horizontal direction and microwire turned by angle Φ, M_t denotes transversal and M_l longitudinal magnetization.

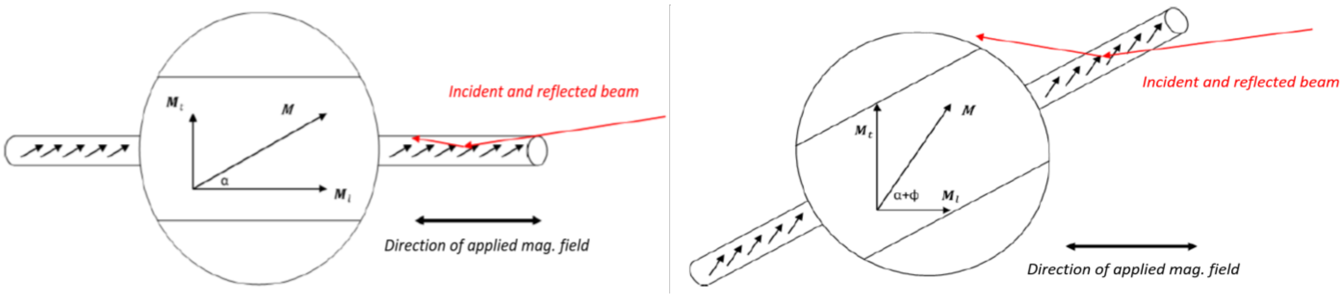

Fig. 6. The situation for microwire in horizontal direction and microwire turned by angle Φ, M_t denotes transversal and M_l longitudinal magnetization components - both change with the angle of rotation of the wire

Relation between the change of magnetization and tilting angle was measured for two specimens. The case of longitudinal magnetization for the first specimen is in Fig. 7 left. The highest maximum pertains to 10° (in clockwise sense), another to 200° (which is the same as 20° off the axial direction in clockwise sense). Regions of signal, where high change of magnetization prevails and regions, where the change is very small are clearly visible. Still, rapid decrease in the signal occurs for a few angles, where the change should be high (in proximity of peaks). That could be caused by inaccuracies due to necessity of slightly move the detector during the measurement. Cylindrical shape of the microwire makes the reflection off the microwire to change its position in space during different phases of rotation. Intensity of the reflected light decreases quadratically with distance, which is why the signal could be smaller even though the change of magnetization is high. To minimize this effect, we made effort to do not change the distance between the detector and a point of reflection when changing the position of the detector. However, a different part of the reflection, which corresponds to a different part of the illuminated area of the microwire, may be incident with the detector after repositioning. Another thing to note is that when the microwire is rotated, area illuminated by the laser beam also changes a bit. Smaller illuminated area infers less light arriving in the detector and therefore a bit smaller signal. In the case of transversal magnetization (Fig. 7 right), we are interested in the minimum of its change at 20° clockwise and 190° clockwise, which corresponds to 10° off axial direction. This matches the results from longitudinal MOKE very well. 90°, 260° and 270° are not displayed in the figures due to the zero change of the transversal magnetization.

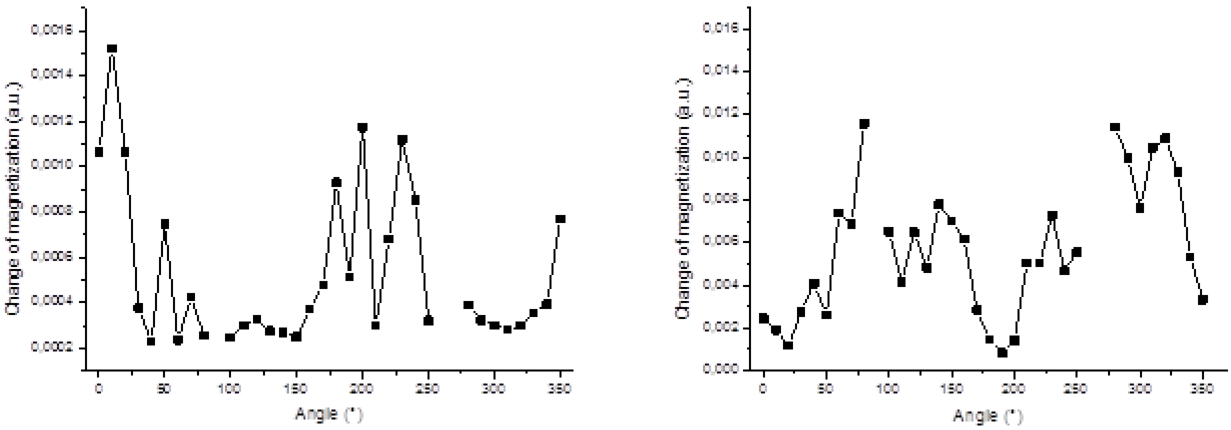

Fig. 7. Dependence of change of the longitudinal (left) and transversal (right) magnetization on angle of rotation (the first specimen)

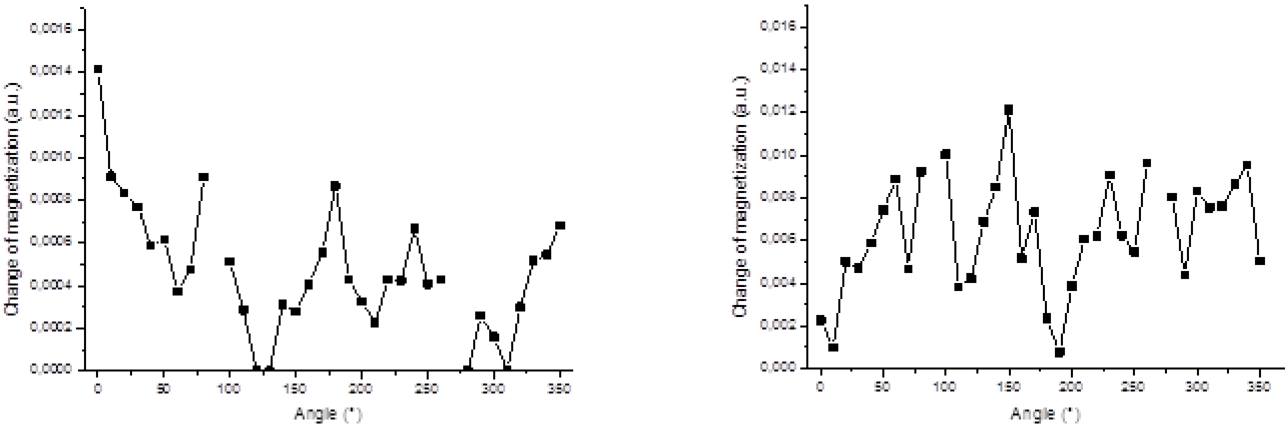

Fig. 8. Dependence of change of the longitudinal (left) and transversal (right) magnetization on angle of rotation (the second specimen)

However, such fact is most probably caused by not reaching the coercive field rather than the change of the transversal magnetization decreases so much and then again increases.

The reason behind this is that when the microwire, initially oriented along the magnetic field, is tilted by 90° or 270° from that direction, it will be magnetized along the hard axis. If corresponding coercive field is not reached, magnetization of the inner core and thereby magnetization of the outer shell will not reverse. It is in an agreement with [7], where critical field for the reversal of transversal magnetization with magnetic field applied perpendicularly to a microwire was for the microwire of the same composition approximately 1990 A/m (diameter of the inner core 15 μm, 9 μm thick glass – coating).

Relation between the change of longitudinal magnetization and the tilting angle for the second specimen is in the Fig. 8 left. It is qualitatively the same as for the first specimen although clear peak is only at 0°. For transversal magnetization, there are again minimums for 10° and 190° in clockwise sense (Fig. 8 right).

5 CONCLUSIONS

We have tested the magneto – optical measurements on microwires and studied the surface magnetization of amorphous glass – coated microwire $Fe_{77.5}Si_{7.5}B_{15}$. For this purpose, the experimental setup allowing precise translation and rotation of specimen in the middle of HC was assembled. Hysteresis loops for the variations of longitudinal as well as transversal component of surface magnetization in different parts of the microwire were obtained through MOKE. Analysis of the hysteresis loops showed that surface magnetization is tilted from the axis of the microwire. The angle between the surface magnetization and the axis of microwire was found. Dependence of the change of longitudinal magnetization on the angle by which the microwire was turned reached the maximum for about 10°. This was supported by complementary results from transversal MOKE.

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