



Surface and bulk magnetic anisotropy in bilayered CoSiB/FeNbCuSiB and FeNbSiB/FeSiB ribbons



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ARTICLE INFO

Article history:

Received 5 October 2015

Received in revised form

16 March 2016

Accepted 23 April 2016

Available online 26 April 2016

Keywords:

Bilayered ribbons

Magnetic anisotropy

Magneto-optical Kerr effect

Vibrating sample magnetometer

Magnetic sensors

ABSTRACT

The present study is devoted to the surface and bulk magnetic anisotropy of the bilayered Co_{72.5}Si_{12.5}B₁₅/Fe_{73.5}Nb₃Cu₁Si_{13.5}B₉ and Fe_{74.5}Nb₃Si_{13.5}B₉/Fe_{77.5}Si_{7.5}B₁₅ ribbons which, completed with microstructure analysis, give the basic complex data prospectively usable for sensor applications. The ribbons prepared by modernized planar flow casting technology were fully amorphous as the X-ray diffraction measurements have confirmed. The thickness of ribbons was about 36 μm while the interlayer thickness reaches typically a few μm as the element distributions at cross-sections have shown. A bending of ribbons leads to changes in both surface and bulk anisotropies detected by the magneto-optical Kerr effect and vibrating sample magnetometer, respectively. An observable difference between both anisotropies is ascribed to the fact that the surface magnetic anisotropy is determined only by magnetostrictive behavior of the corresponding individual layer while the bulk anisotropy depends on integral properties of both layers and the interlayer. Moreover, the magnetic measurements at room and elevated temperatures have shown that the bulk magnetic properties are more markedly influenced by the composition of iron rich layers, FeSiNbCuB or FeSiB, being during the casting in contact with air.

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1. Introduction

The technologies, materials, and constructions of various types of sensor elements are still on the top of interest. The frequent applications include manufacturing and machinery, airplanes and aerospace, cars, medicine and robotics [1,2]. Technological progress allows more and more sensors to be manufactured using new materials and/or technologies on a microscopic scale [3]. One of possibilities, as a candidate for sensor sensitive applications, offers also the bilayered and/or multilayered functional materials. Recently, the technology of planar flow casting, well-known from the production of amorphous and/or nanocrystalline single-layered ribbon type materials [4], was innovated by a double nozzle [5]. The first attempts to produce bilayered ribbons with a combination of

dissimilar amorphous materials based on Fe, Ni, and Co and to investigate their structural and physical properties from the viewpoint of sensor applications can be found in literature. Owing to the fact that the bilayered alloys have to be compatible from the viewpoint of their flow characteristics and melting points not too many various systems have been prepared up to now [6–10]. Moreover, it turns out that the layer compositions determine the brittleness, cracking resistance, and bend sensitivity since the bending of bilayered ribbon induces a tensile stresses in the top layer and compressive stresses in the bottom layer. It implies that the layers of suitable magnetostrictions can positively influence the tensile-compressive properties and determine the resulting sensitivity during bending.

Our previous studies were focused on CoSiB/FeSiB ribbon [10] and on CoFeCrSiB based bilayered ribbon of dissimilar Co/Fe content in layers [11,12], both rather brittle. Two bilayered ribbons of the slightly different compositions, CoSiB/FeSiNbCuB and FeNbSiB/FeSiB, are investigated in the present study. In comparison to the previous bilayered alloys the present compositions exhibit at first

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sight a markedly better toughness and cracking resistance during bending. Therefore, the microstructure and magnetic characteristics supported by the magnetic domain observations are studied in detail from the viewpoint of the surface, interface, and bulk in the as-prepared state of ribbons. The obtained results are completed by the surface and bulk anisotropy variable in dependence on ribbon-coiling diameter and correlated with magnetostrictions of individual layer compositions.

2. Experimental

The bilayered ribbons of compositions $\text{Co}_{72.5}\text{Si}_{12.5}\text{B}_{15}/\text{Fe}_{73.5}\text{Nb}_3\text{Cu}_1\text{Si}_{13.5}\text{B}_9$ (Co/Fe) and $\text{Fe}_{74.5}\text{Nb}_3\text{Si}_{13.5}\text{B}_9/\text{Fe}_{77.5}\text{Si}_{7.5}\text{B}_{15}$ (Fe/Fe), 36 μm thick and 8 mm wide, were prepared by planar flow casting (PFC) method using the crucible divided into two chambers ended by nozzles of the same geometry. The setup of the two-chamber crucible was adjusted so that the melts of CoSiB or FeNbSiB were ejected directly on the rotating wheel immediately followed by the melts of the FeNbCuSiB or FeSiB. In such a way, the $\text{Co}_{72.5}\text{Si}_{12.5}\text{B}_{15}$ and the $\text{Fe}_{74.5}\text{Nb}_3\text{Si}_{13.5}\text{B}_9$ layers were during production in contact with the rotating wheel (wheel side; *w*), while the opposite $\text{Fe}_{73.5}\text{Nb}_3\text{Cu}_1\text{Si}_{13.5}\text{B}_9$ and the $\text{Fe}_{77.5}\text{Si}_{7.5}\text{B}_{15}$ layers were in contact with the surrounding atmosphere (air side; *a*). The individual layers are characterized by different magnetostriction coefficients. The magnetostrictions of the $\text{Co}_{72.5}\text{Si}_{12.5}\text{B}_{15}$ and $\text{Fe}_{77.5}\text{Si}_{7.5}\text{B}_{15}$ single-layer samples were obtained using a direct measuring method in the high magnetic fields [13] and published in Ref. [14]. The magnetostrictions of the $\text{Fe}_{73.5}\text{Nb}_3\text{Cu}_1\text{Si}_{13.5}\text{B}_9$ and $\text{Fe}_{74.5}\text{Nb}_3\text{Si}_{13.5}\text{B}_9$ single-layer samples were obtained by the same method [13] and not published up to now. The values are summarized in Table 1.

X-ray diffraction (XRD) patterns from both wheel (*w*) and air (*a*) sides of the ribbon type samples were measured by the X'Pert powder diffractometer with $\text{CoK}\alpha$ radiation ($\lambda = 1.789 \text{ nm}$) in Bragg-Brentano geometry to check the microstructure.

TESCAN LYRA 3XMU FEG/SEM scanning electron microscope (SEM) with an Oxford Instruments energy dispersive X-ray (EDX) analyzer X-Max 80 applying the accelerating voltage of 20 kV was used for observation of the microstructure morphology and measurement of element distributions along the cross-section of samples. For this purpose a sample holder depicted schematically in Fig. 1 was used. The sample was fixed in a vertical position by a plastic clamp and subsequently as a whole in resin providing sufficient stability and stiffness. The cross-section of the fixed sample could be then polished to guarantee good surface smoothness. The ribbon fixation was also suitable for the magneto-optical observation.

Atomic Force Microscopy (AFM) using Ntegra Prima platform (NT-MDT) at ambient conditions has allowed to observe topography of the sample surfaces using the semi-contact/lift mode and to obtain information concerning the surface roughness. The tip used for AFM measurements was coated with CoCr magnetic film approximately 30–40 nm thick. The curvature radius of the tip was about 40 nm.

The surface magnetic properties were investigated by the magneto-optical Kerr effect (MOKE) methods [15]. MOKE hysteresis

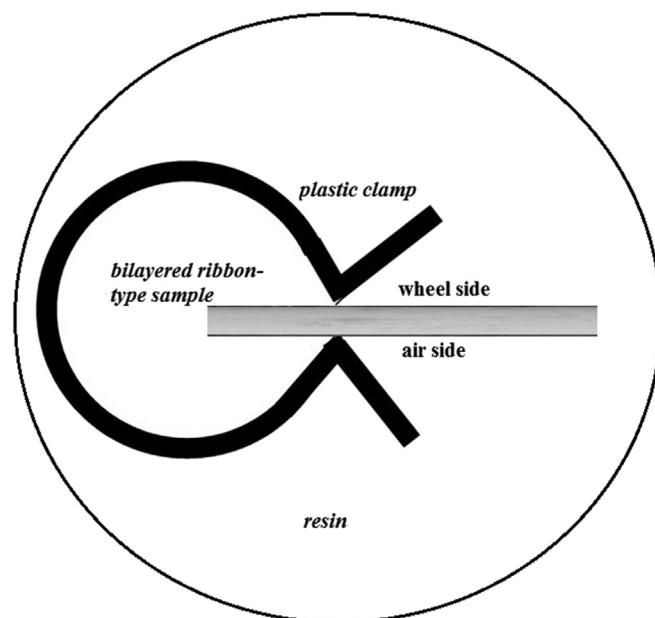


Fig. 1. Sample holder for the cross-section scanning electron microscopy observation.

loop represents a dependence of the magneto-optical angle of the Kerr rotation on the applied magnetic field. The magneto-optical (MO) angle is the angle between the polarizations of the light incident at and reflected from the ribbon surface. The measurements bring the information from the small surface volume determined by the penetration depth of the light (about 20 nm) and the beam diameter (0.3 mm). The magnetic domain structure observed on a surface and on the sample cross-section including interface between the layers [11] was examined using the Zeiss optical microscope adapted for the magneto-optical Kerr effect. The MOKE investigations of the mechanically stressed samples have required a special sample holders having half-round-end of diameter *D* 25, 20, 15, and 13 mm schematically depicted in the left panel in Fig. 2. The ribbon sample was fixed on it and MOKE measurements were done on the outer tensile stressed surface. The measured MO angles are sensitive to the in-plane longitudinal magnetization component M_L that is parallel to the applied magnetic field and to the plane of the light incidence.

Bulk hysteresis loops and thermomagnetic (TMC) curves were obtained using the vibrating sample magnetometers (VSM) Microsense EV9 and EG&G Princeton Applied Res. Corporation. Hysteresis loops of the unstressed and stressed samples were measured in the magnetic fields up to $\pm 100 \text{ kA/m}$ in configuration schematically shown in the right panel in Fig. 2. TMC of the unstressed samples were obtained in the constant magnetic field of 4 kA/m, by the temperature increase (decrease) of 4 K/min from the room temperature (RT) up to 1100 K and back in Ar atmosphere to prevent sample oxidation.

3. Results and discussion

3.1. Microstructure and topography

3.1.1. Bulk and cross-section microstructure

The X-ray diffraction (penetrating depth about 10 μm) patterns, taken with high statistics, did not show any extraordinary features as seen in Fig. 3. They have consisted of two broad diffraction lines close to $2\theta = (52\text{--}53)^\circ$ and $(96\text{--}98)^\circ$ the peaks of which were slightly shifted in dependence on layers compositions. Evidently

Table 1

The composition and magnetostriction coefficients, λ_s , of the bilayered samples.

Ribbon	Layer	Side	λ_s (ppm)
Co/Fe	$\text{Co}_{72.5}\text{Si}_{12.5}\text{B}_{15}$	wheel	−2.6 [14]
	$\text{Fe}_{73.5}\text{Nb}_3\text{Cu}_1\text{Si}_{13.5}\text{B}_9$	air	+18.0
Fe/Fe	$\text{Fe}_{74.5}\text{Nb}_3\text{Si}_{13.5}\text{B}_9$	wheel	+11.8
	$\text{Fe}_{77.5}\text{Si}_{7.5}\text{B}_{15}$	air	+32.0 [14]

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