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Structural investigation of $TbCo_2$/Fe magnetostrictive thin films by tomographic atom probe and Mössbauer spectrometry

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Abstract

Sputtered $TbCo_2$/Fe magnetostrictive multilayers have been deposited on both island posts and flat substrates and analysed by laser-assisted tomographic atom probe and ^{57}Fe Mössbauer spectrometry. The three-dimensional reconstructions of the layers were obtained, allowing the analysis of the interfaces. Differences are revealed, as the Fe-on-$TbCo_2$ interface is thinner than the $TbCo_2$-on-Fe interface. This effect is attributed to Fe/Co interdiffusion, controlled by the establishment of the Tb layer. Fe layers are well crystallized.

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Keywords: Magnetostrictive multilayer; Tb–Co–Fe; Tomographic atom probe; Mössbauer spectrometry

The need for microactuator applications has stimulated the development of thin films with a large magnetostriction. In the case of multilayers, the exchange coupling between layers with a large room temperature magnetostriction, such as terfenol $TbFe_2$, and layers with a high magnetisation and soft magnetic properties, such as Fe or Fe–Co, reduces the saturation magnetostriction, but decreases notably the saturation field [1], allowing the integration of the driving magnetic source in the microsystem [2].

Due to interdiffusion between adjacent layers during deposition, multilayers have generally compositionally modulated interfaces. So, for small thicknesses, the properties of the multilayers strongly depend on both the thickness of the layers and the interface roughness. This was evidenced for magnetic properties such as perpendicular magnetic anisotropy in Fe/Tb multilayers [3,4].

We investigated, the structure of the interface in a $TbCo_2$/Fe magnetostrictive multilayer, by three-dimensional laser-assisted tomographic atom probe (3D LaTAP) and ^{57}Fe Mössbauer spectrometry. 3D LaTAP, which allows a 3D reconstruction of the analysed volume at the atomic scale, is a powerful technique to investigate metallic layers of a few nanometers thickness in terms of both chemical nature (morphology) and atomic-scale (structural) features such as layer roughness [5]. Mössbauer spectrometry allows to obtain informations on both structure and magnetic texture of the Fe atoms.

The $TbCo_2$/Fe multilayer was deposited onto both flat silicon wafer substrate and silicon island posts by the RF-sputtering method, using a modified and automated Leybold Z550 equipment in a clean-room environment. The nominal thicknesses are 20 and 25 nm for the $TbCo_2$ and Fe layers, respectively. As the 3D-LaTAP analysis requires needle-shaped specimens, the multilayers deposited on island posts were thinned by focused ion beam in a scanning electron microscope. Details about the deposition procedure, the thinning procedure and the 3D LaTAP analysis conditions can be found in Ref. [6]. Mössbauer spectrometry analysis was performed at room temperature in transmission geometry using a ^{57}Co source in a rhodium matrix.

3D elemental mappings of Fe, Tb and Co atoms in the multilayer deposited onto an island post are shown in Fig. 1, within an analysed volume of about $(15 \times 15 \times 100)\,nm^3$.

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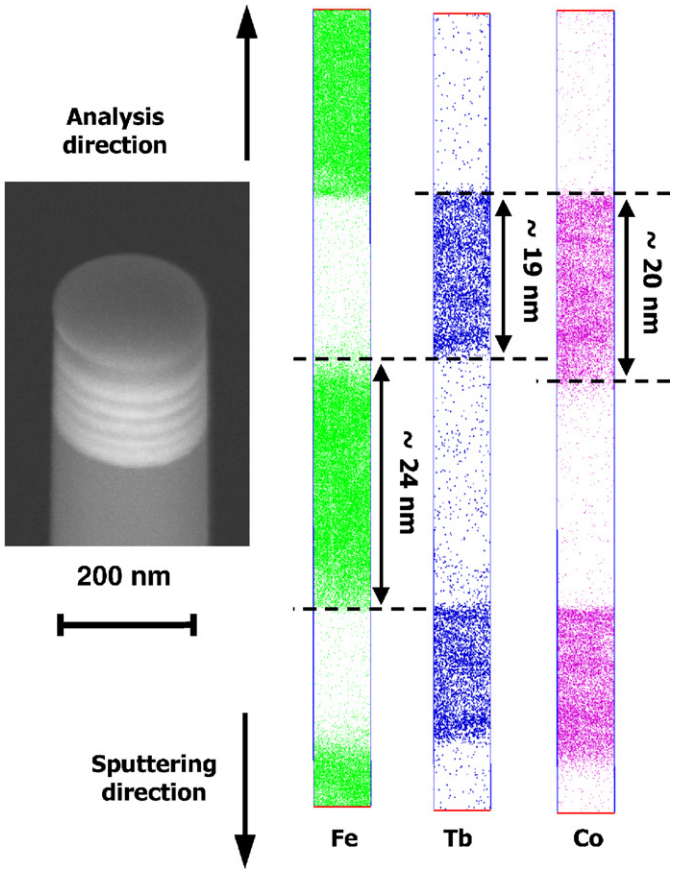

Fig. 1. Scanning electron microscopy image of the multilayer deposited on an island post (a protective Cr layer can be seen at the top), and 3D elemental mappings of Fe, Tb and Co atoms in the multilayer.

The interfaces between Fe and Tb layers and between Fe and Co layers are clearly seen from the change in concentrations of the elements. The Fe-on-Tb and Fe-on-Co interfaces are located at the same place. However, on the other side, the Tb-on-Fe interface is shifted relatively to the Co-on-Fe interface. Consequently, the thicknesses of Co and Tb (measured at half concentration width of each element) are different.

In the core of the Fe layers, the Fe atomic concentration is close to 100%. In the $TbCo_2$ layers, Fe atoms are detected, with low atomic concentrations (less than 3%), the Co concentration is close to what is expected (63%), but the Tb concentration is less than expected (25%). The composition measurement of Tb during the analysis can be affected by selective loss of Tb, due to burst evaporation [7], or to multihit events [8].

The Fe-on-$TbCo_2$ interface is well defined with a weak interdiffusion of Fe and Co (1 nm). However, the $TbCo_2$-on-Fe interface is not well defined: the Tb-on-Fe interface is thin (about 1 nm), but the Co-on-Fe interface is much larger (about 4 nm). Then, it appears that the diffusion of Fe and Co at the Fe-on-$TbCo_2$ interface is limited. This is attributed to the fact that the Tb layer is well established at the Fe-on-$TbCo_2$ interface, thus acting as a diffusion barrier for Fe and Co. At the Fe-on-$TbCo_2$ interface, Co atoms diffuse in the Fe layer during the formation on the first Tb monolayer, until the establishment of the Tb layer, which then acts as a diffusion barrier and the Fe/Co interdiffusion is stopped.

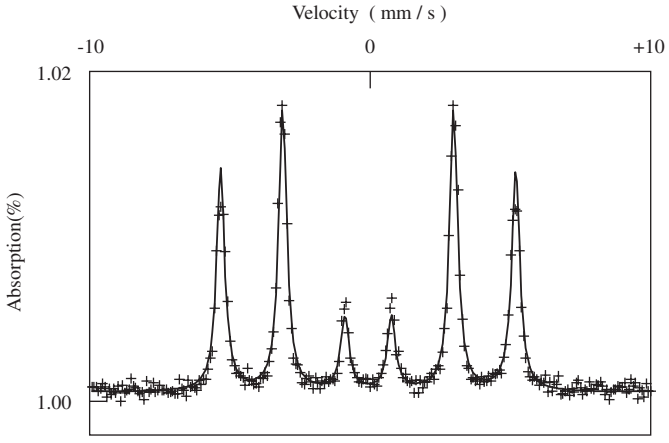

Fig. 2. Room temperature Mössbauer spectrum of the multilayer.

The Mössbauer spectrum of the multilayer deposited onto a flat substrate is shown in Fig. 2. The magnetic contribution of α-Fe is the only contribution fitted. This shows that almost all the Fe atoms are present in crystallized Fe layers. The contribution of the Fe atoms at the interfaces is negligible. This is in agreement with the results of the 3D LaTAP analysis.

The 3D LaTAP analysis of sputtered $TbCo_2$/Fe multilayers deposited on island posts allows to reveal differences in the interfaces. The Fe-on-$TbCo_2$ interface is thinner than the $TbCo_2$-on-Fe interface. This result is interpreted by considering the role of the establishment of the Tb layer on Fe/Co interdiffusion. As shown by ^{57}Fe Mössbauer spectrometry, the Fe layers are well crystallized.

The characterization of the structural properties of the sputtered $TbCo_2$/Fe multilayers will help in understanding their magnetic and magnetostrictive properties. This investigation is in progress.

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