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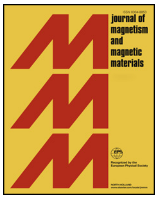

Research articles

Structure and magnetic properties of Tb-Co/Ti and Tb-Co/Al_2O_3 multilayers

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ABSTRACT

The influence of the nanoscale thicknesses of the ferrimagnetic Tb-Co layers on the structure and magnetic properties of magnetron sputtered Tb-Co/Ti and Tb-Co/Al_2O_3 magnetic multilayers were comparatively studied. Low angle X-ray diffraction patterns testified to the existence of a well defined layered structure in all the cases under consideration. For all samples, the magnetization was positioned in the plane of the films in the entire investigated temperature interval from 5 to 350 K. The temperature dependence of magnetization of the multilayered structures is the function of the Tb-Co layer thickness. The material of the spacers was shown to significantly influence the magnetic properties of the multilayers.

1. Introduction

Tb-Co amorphous films and Tb-Co-based magnetic multilayers with non-magnetic thin spacers have attracted attention for decades due to their high potential in magneto-optical recording, microdevices and sensor applications [1–6]. A new wave of interest in recent years in these kind of magnetic films is associated with the all-optical switching research direction [7–9]. In amorphous Tb-Co films, the magnetizations of the Co and Tb sub-lattices are exchange coupled antiferromagnetically and different temperature dependences of magnetization correspond to each one of the sub-lattices. For Tb-Co alloy compositions in the interval of 15–30 at.% Tb, the existence of such difference of temperature dependences leads to the appearance of a magnetic compensation state and the existence of a compensation temperature (T_{comp}), for which the magnetizations of both sub-lattices are equal in magnitude and opposite in direction [10]. Over the years, the properties of amorphous rare earth-transition-metal (RE-TM) films have thoroughly been studied by different techniques. Therefore, knowing the composition of the film, it is possible to predict its magnetic properties, in particular, such important parameters as the Curie temperature (T_C) and compensation temperature [10]. Conversely, knowing T_C and T_{comp} one can estimate the composition of the sample. However, these previously reported data were obtained for relatively thick films, of the order of 1 µm. It is known, that the thickness of the layers has an appreciable effect on the magnetic properties of ferromagnetic films in the nanometer to tens of nanometers range of thicknesses [11–14]. The origin of this effect (known as finite-size effect) seems to be connected with the reduced number of atoms in the direction perpendicular to the magnetic thin film plane leading to a decrease of the total value of the magnetic exchange energy [15]. In addition, the magnetic properties of Tb-Co-based multilayers can be modified by the material of non-magnetic spacers [16,17].

In the present work, the role of the thickness of the ferrimagnetic Tb-Co layers in the formation of the magnetic properties of Tb-Co-based multilayers with conductive and insulating spacers was studied.

2. Experimental procedure

Tb-Co/Ti and Tb-Co/Al_2O_3 magnetic multilayers were deposited by magnetron sputtering at room temperature onto Corning glass substrates. The background pressure before the deposition was 3×10^{-7} mbar. The deposition was performed in an Ar atmosphere with 2×10^{-3} mbar working pressure. The Tb-Co layers were obtained by dc magnetron sputtering from element targets. The Al_2O_3 layers were deposited using an Al_2O_3 composition target. The deposition rates were 7.9 nm/min for Tb-Co layers and 1.8 nm/min for Ti and Al_2O_3 layers. The thickness of the Tb-Co layers ($L_{Tb\text{-}Co}$) was varied in the interval of 200–3 nm. The thickness of Ti and Al_2O_3 spacers was kept constant – 2 nm in both cases. A magnetic field of 100 Oe was applied during sample preparation parallel to the substrate surface in order to induce a well defined uniaxial magnetic anisotropy with a low distribution of local effective anisotropy axes. The compositional ratio of

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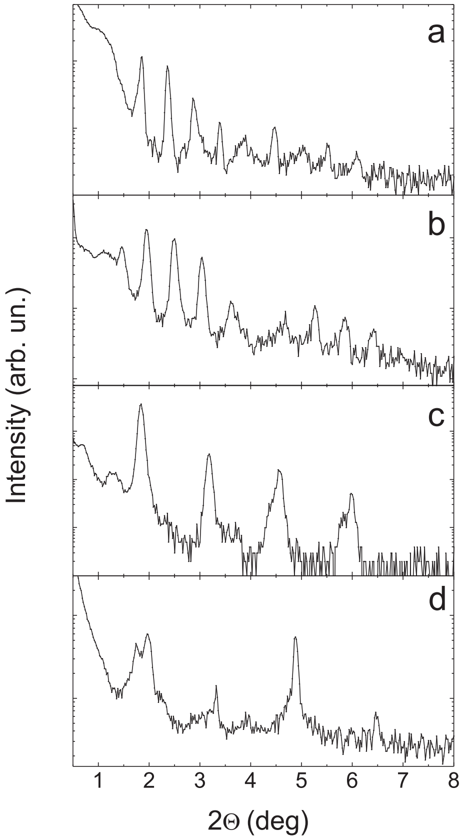

Fig. 1. Low-angle X-ray diffractograms for the [Tb-Co(12 nm)/Ti(2 nm)]$_{10}$ (a), [Tb-Co(12 nm)/Al$_2$O$_3$(2 nm)]$_{10}$ (b), [Tb-Co(3 nm)/Al$_2$O$_3$(2 nm)]$_{30}$ (c) and [Tb-Co(3 nm)/Ti(2 nm)]$_{30}$ (d) multilayer samples.

Tb and Co in the Tb-Co layers was determined by energy dispersive X-ray spectroscopy (EDX) detection using a scanning electron microscope. The microstructure was studied by X-ray diffraction (XRD) using Cu-K$_\alpha$ radiation. Low angle X-ray diffraction was used to determine the quality of the layered structure. Low angle XRD data were collected on a Bruker D8 Advance diffractometer equipped with a Cu tube, Ge(1 1 1) incident beam monochromator ($\lambda = 1.5406$ Å) (fixed slit of 1 mm) and a Sol-X energy dispersive detector (fixed slit of 0.06 mm). Magnetic measurements were performed with a SQUID magnetometer in the temperature range of 5–380 K.

3. Results and discussion

Fig. 1 shows selected characteristic examples of the low-angle X-ray diffractograms for the [Tb-Co (12 nm)/Ti (2 nm)]$_{10}$, [Tb-Co (12 nm)/Al$_2$O$_3$ (2 nm)]$_{10}$, [Tb-Co (3 nm)/Al$_2$O$_3$ (2 nm)]$_{30}$ and [TbCo (3 nm)/Ti (2 nm)]$_{30}$ magnetic multilayered structures.

It should be noted that the general features of the spectrum do not depend on the spacer material. Low-angle X-ray diffraction profiles allow to evaluate multilayer periodicity in detail. The period for each type of multilayer can be precisely determined by a modified Bragg's law as it was earlier proposed by Sugawara et al. [18]: $d = \Lambda[1 - (1 - n_{SL})/\sin^2 \theta_n)]$, where $d = n\lambda/\sin \theta_n$. Here Λ is the period of the multilayered structure, n the interference peak order, λ the X-ray wavelength, θ_n the angle for the diffraction peak, and n_{SL} is the average X-ray refraction index of the multilayered structure. The values of the period of the multilayers under consideration determined by low angle X-ray diffraction (14 nm and 5 nm) were in good agreement with the expected values of the period calculated from the deposition time. The presence of well defined XRD peaks even for the samples with the smallest thickness of 3 nm of Tb-Co layers confirms the existence of a well defined layered structure in all of the studied cases.

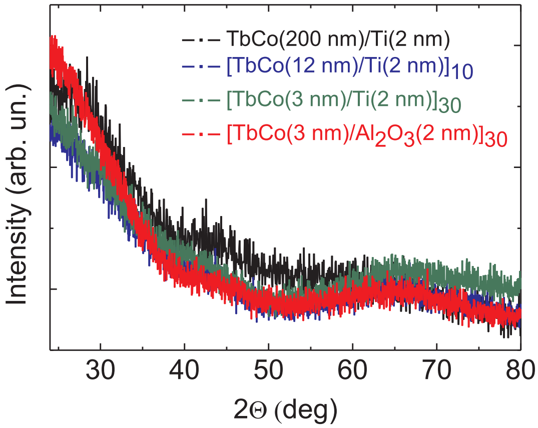

Fig. 2. X-ray diffractograms for selected samples.

Fig. 2 shows an example of the X-ray diffraction spectra for selected samples. These measurements show that the Tb-Co layers in the Tb-Co/Ti and Tb-Co/Al$_2$O$_3$ multilayers were X-ray amorphous at all $L_{\text{Tb-Co}}$ values – no well defined peaks were observed.

According to the EDX analysis, the amount of terbium was 19 at.% for the thick Tb-Co (200 nm) films. Taking into account this composition and the dependence of the compensation temperature on the composition [10], it can be assumed that T_{comp} for the thick Tb-Co (200 nm) films should be as high as approximately 200 K. Our measurements of $M(T)$ dependence confirmed this estimation (Fig. 3).

It is considered that near the state of magnetic compensation, Tb-Co films can have perpendicular magnetic anisotropy [8,10,16]. However, in all our samples regardless of the spacer type, the magnetization is in the plane of the films for the whole temperature interval under consideration. Fig. 4 shows an example of the in-plane and out-of-plane hysteresis loops for [Tb-Co (12 nm)/Ti (2 nm)]$_{10}$ multilayers. The shape of the hysteresis loops is another confirmation that the formation of perpendicular magnetic anisotropy in RE-TM films depends on many factors, including the conditions for their preparation [17].

Let us return to Fig. 3, where the temperature dependences of the magnetization measured in 10 kOe on various Tb-Co/Ti samples are presented. A clear minimum was observed for all curves. This minimum corresponds to the compensation temperature, at which the mutually antiparallel Tb- and Co-sub-lattice contributions to the net magnetization are equal to each other. It should be noted that a decrease of the thickness of the Tb-Co layers leads to a shift in the position of the minimum towards higher temperatures. The dependence of $T_{\text{comp}}(L_{\text{Tb-}}$

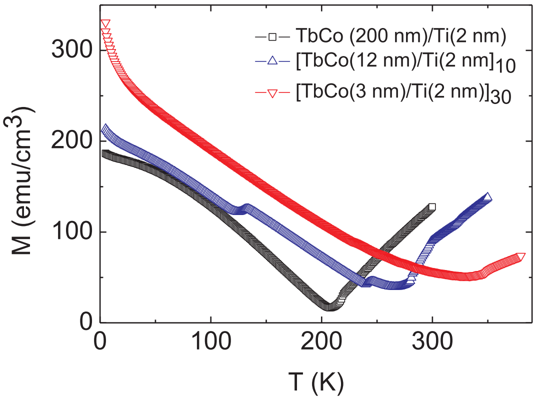

Fig. 3. Temperature dependence of the magnetization for the thick Tb-Co (200 nm) film and various samples with Ti spacer. For this measurement an external field of 10 kOe was applied along the same direction of the field applied during sample preparation.