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A Study of Magnetic Properties for Sputtered Amorphous Films Tb-Co Based Alloys

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Abstract: The study describes a study on the magnetic properties of amorphous $Tb_{1-x}Co_x$ binary films prepared by sputtering. Results are given for the composition dependence of Curie temperature and magnetisation on the room temperature. The aim of this work is to study the magnetic properties of $Tb_{1-x}Co_x$ amorphous alloys with respect to the composition. Magnetisation processes have been studied over a wide range of fields (up to 8 Tesla) and temperature range (10-300 K) by using a vibrating sample magnetometer (VSM). The magnetic properties for $Tb_{1-x}Co_x$ have been investigated in a range of $0.48 \leq x \leq 0.78$. We have found a large anisotropy at room temperature with ordering temperatures up to about 600 K. For the samples which are ferromagnetic at room temperature (i.e., x >_0.62). The hysteresis loops describe the intrinsic anisotropy which can be analysed in terms of a biaxial anisotropy. No saturation was observed for fields up to 8 T due to the sperimagnetic nature of such materials.

Key words: Magnetic field, amorphous material anisotropy, magnetisation, amorphisation

INTRODUCTION

The magnetic structures of the rare earth-transition metal amorphous alloys have been intensively studied[1-6]. Among all studied properties, the magnetisation and the shape of hysteresis loops are dependent upon the alloy composition, heat and mechanical treatment. The random anisotropy model of Harris and *al*[7] describes the competition between exchange interactions and random anisotropy in amorphous alloys. The model accounts for the sperimagnetism, i.e., the non collinear arrangement of rare-earth magnetic moments in 3d-4f alloys and this is due to the large random anisotropy of rare-earth atoms (R).

These amorphous alloys are characterised by large magnetic domains, so-called Imry and Ma domains[8]. In the case of magnetism, the amorphous state changes the magnetic properties because of the narrow relation ship between crystallographic and magnetic structure. However, in first approximation the mean magnetic moment does not depend upon the surrounding atomic arrangement but depends on chemical composition in either crystallised or amorphous state. As an example, Critical content alloys for magnetic disappearance in amorphous is greater than in crystal[9].

Thus, it is interesting to consider the R-Co_2 alloys in the crystalline state where their Curie-temperatures are

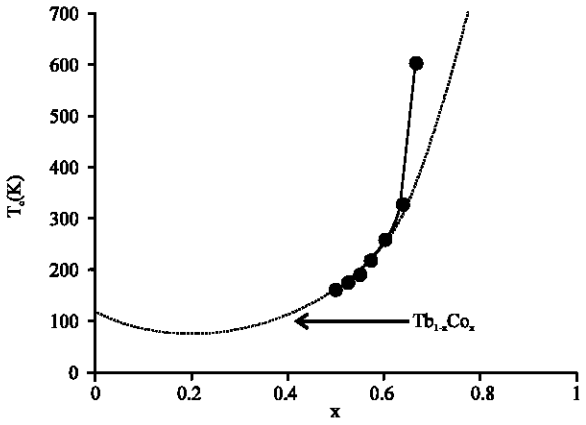

Fig. 1: Curie temperature for a-$Tb_{1-x}Co_x$ as a function of the composition x

below the room temperature, while the reported results on amorphous state show very high ordering temperatures up to 600 K for x >_0.68 (Fig. 1). This was explained in term of band narrowing in the amorphous state which renders the Co-sub lattice strongly magnetic at room temperature resulting from the well-defined ferromagnetic coupling of the Co moments[10].

The goal of the present work is to describe the magnetic properties in the $Tb_{1-x}Co_x$ amorphous alloys with various compositions. Changes of the composition will be caused an influence on magnetisation process, magnetic

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anisotropy and sperrimagnetic. $Tb_{1-x}Co_x$ amorphous thin films are chosen as the material of study because of its relatively high Curie temperature and its good resistance against oxidation.

MATERIALS AND METHODS

The $Tb_{1-x}Co_x$ films were deposited by co-sputtering from two different targets in a DC triode sputtering machine (Fig. 2a). The composition of these two targets (Tb_2Co and $Tb\text{-}Co_4$) was chosen in order to prepare alloys in a small range around (x= 0.6-0.8) which allowed a variation of composition across the substrate holder of $0.48 \leq\_ x \leq 0.78$.

The Fig. 2b is presented the composition dependence with the position in the sample holder. A numerical calculation and RBS measurements were compared and we observe a good agreement of values. The silicium (Si) substrates were used in form of squares (the sizes is 5x5 mm^2) with a 150 μm thickness for magnetisation measurements.

Film thickness were determined using an α-step profiles meter and from RBS analysis. Thickness of samples varied between 2000 Å and 5000 Å. Thickness values given by RBS were systematically about 10-15% smaller than that of the α-step and can be attributed to the lower density of the sputtered films compared to their bulk equivalent. The chemical composition of alloys was obtained also by RBS.

The samples was characterised by the X-ray diffraction and using Kα-ray of cooper with λ_{Cu}= 0.15405 nm and formula of 2θ. All the sputtering films show the common shape of the X-ray patterns from amorphous alloys. Its consist only on maximum close to 48° without sharp peaks as described in early work[4,5].

The magnetisation measurements were determined by using a (VSM) Vibrating Sample Magnetometry in fields of up to 8 T and at temperatures between 10 K and 300 K. Hysteresis loops (in fields up to ±0.3 T) and magnetisation curves up to 1.9 T were determined in the film plane. Successively, types of measurements were carried out, First the magnetic field parallel to the measurement direction, Secondly the magnetic field perpendicular to the measurement direction.

RESULTS AND DISCUSSIONS

The ordering temperatures were determined using Arrot plots. The values obtained are in good agreement with those found by other author as shown in Fig. 1[10]. Samples with x <0.62 were found to order ferromagnetic

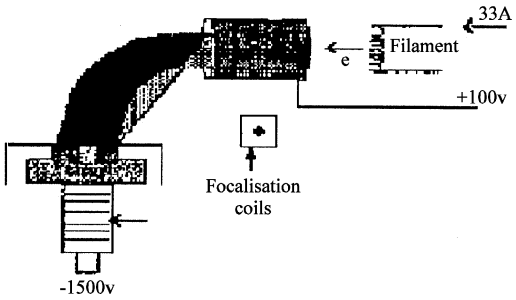

Fig. 2a: DC triod co-sputtering configuration

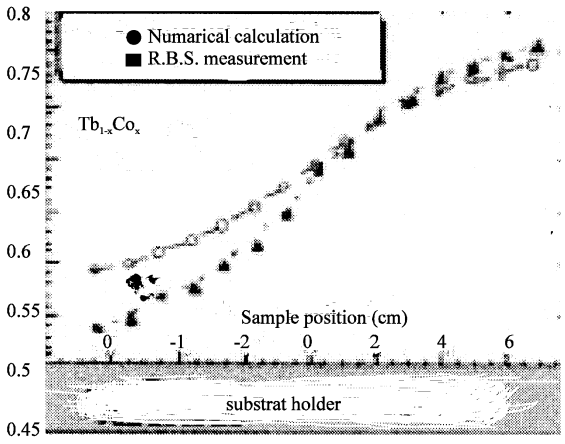

Fig. 2b: compared numerical calculations and RBS measurements of cobalt content in $Tb_{1-x}Co_x$ with respect the position along substrate holder

below 300K. On the other hand, for x >0.62 magnetisation curves were measured at 300 K in two directions along easy and hard axis in the plane of the sample. The Tb rich samples are magnetically very soft with low coercivity and low remanence (as $Tb_{0.34}Co_{0.66}$, not shown). The magnetisation lies in the plane of the sample with a very small anisotropy (small M_R/M_s). This is consistent with the fact that these materials are close to their ordering temperature. With the increasing Co content (as $Tb_{0.26}Co_{0.74}$), the coercive field H_c and the relative anisotropy M_R/M_s increase: This can be explained by the competition which occurs between well defined in-plane anisotropy and a perpendicular anisotropy regime. This is a bi-axial anisotropy regime where there are competing in-plane and perpendicular anisotropy terms[11]. A growing perpendicular anisotropy is observed in the Co rich Tb-Co samples as is observed also for the Tb-Fe thin films[12].

For the considered samples, the results do not show saturation even up to 8 T. At room temperature, samples which corresponds to the composition around x = 0.62 are paramagnetic. For the ferromagnetically ordered

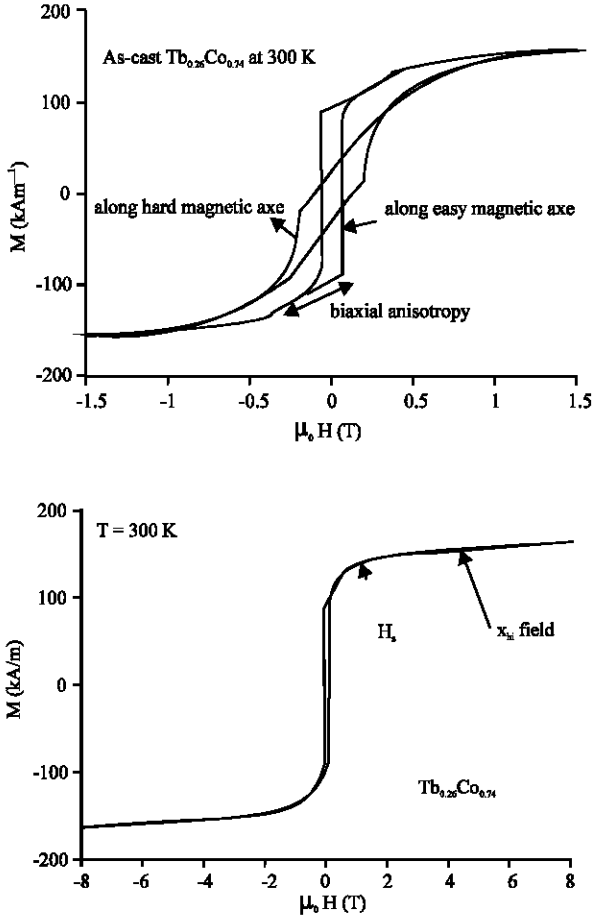

Fig. 3: Magnetisation loops at 300 K for $Tb_{0.26}$ $Co_{0.74}$ in 2 directions Insert: High field magnetization up to 8 Tesla

samples, a high field susceptibility χ_{HF} arises from the sperimagnetic distribution of Tb moments and the progressive closing of the Tb-cône with the increase of the field (Fig. 3). Such a cone structure arises from the competition between the random anisotropy and the exchange interactions[13,14].

Thus, in what follows, we define a spontaneous magnetisation, M_s, from the high field data extrapolated to H=0 and in a similar way we define the saturation field H_s to be the field at which the domain structure is saturated. The saturation magnetisation M_{sat} is then defined at H_s.

The results from Fig. 1 can already be found in Fig. 4[15]. The spontaneous magnetisation M_s of samples at 300 K is shown in Fig. 4 as a function of x. We see that M_s decreases as x increases, this is the fact of the antiparallel coupling of the Tb and Co moments in which the Tb moments are dominant. From this behaviour the composition compensation at room temperature 300K

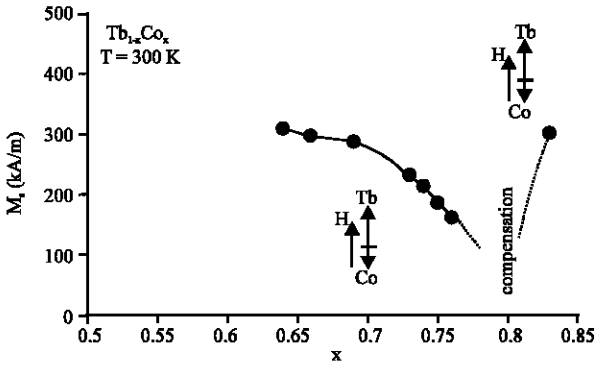

Fig. 4: Spontaneous magnetisation $M_s$at 300 K as a function of the composition $Tb_{1-x}Co_x$

(extrapolated at 0 Tesla) is x = 0.8 corresponds to the compensation between magnetic moments of Tb and Co[6,13].

In general, the maximum magnetisation found in the amorphous state for Tb-M alloys is lower than in the crystalline state. There are two reasons for that: i) some compositions have a lower ordering temperature in the amorphous state which means that the magneto crystalline anisotropy is lower; i i) the sperimagnetic arrangement of the Tb-moments in the amorphous state gives rise to a distribution of the Tb-moments which reduces the projected magnetisation as explained elsewhere[14].

In sperimagnetic systems, domains of correlated moments are formed as result of the competition between exchange interactions and random local anisotropy. These domains, termed Imry and Ma domains[8,16], are oriented more or less at random in zero field and have a spatial dimension which is proportional to the ratio of the local anisotropy energy K_{loc}, to the exchange energy E_{ex}. This competition leads to the occurrence of Imry and Ma domains of size 10^{-7}m for $Tb\text{-}Co_3$[17]. The corresponding magnetic structure can be imagined as a distribution of the rare earth magnetic moments on a surface of a cone where the magnetisation is assumed to be proportional to $<\alpha_z>$ i.e. an average over this cone of the direction cosines, α_z, of the local magnetic moments[18]. A similar analysis was carried out for these Tb-Co films after the film stresses were relieved by annealing under field. The perpendicular anisotropy disappeared completely in Tb-Co films after annealing.

CONCLUSION

We have investigated a series of amorphous thin film $Tb_{1-x}Co_x$ in the range of $0.48 \le x \le 0.78$. Samples showed a high T_c which rises with Co content. The sperrimagnetism

of these alloys is confirmed, which is due to the magnetic hardness of these materials and to bi-axial anisotropy in the film plane.

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