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MAGNETIC PROPERTIES AND ANISOTROPY OF GdFe AMORPHOUS THIN FILMS

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Two types of Gd-Fe amorphous thin films, one Fe-rich ($Gd_{0.21}Fe_{0.79}$) and the other Gd-rich ($Gd_{0.46}Fe_{0.54}$), have been studied by magneto-optical transversal Kerr effect and by torque magnetometry. The samples were measured at different temperatures before and after annealing. Changes in the magnetisation were observed in both samples after annealing. In addition the Gd-rich film shows a perpendicular magnetic anisotropy at low temperatures after heat treatment at 350° C. However in the case of Fe-rich film there was no change in the magnetic anisotropy after the annealing.

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1. Introduction

Amorphous thin films and multilayers consisting of rare earth (RE) and transition metals (TM) with perpendicular magnetic anisotropy are the most appropriate material for magneto-optical applications [1-3]. These materials are widely used in many technological applications. Therefore the production and characterisation of these materials attracted special attention from both the fundamental and technological viewpoints. The main theoretical aspect of this field is the origin of the perpendicular magnetic anisotropy, PMA. The origin of the PMA and therefore the possibilities of a precise control of the parameters responsible for it, have been intensively studied during the last 10 years, but they are not yet clear [4-7].

In this paper magnetic properties and magnetic anisotropy of thin GdFe films of two types were studied just after thermal evaporation deposition and additional heat treatment. The first type is Fe-rich ($Gd_{0.21}Fe_{0.79}$) and the second one is Gd-rich ($Gd_{0.46}Fe_{0.54}$).

2. Experimental procedure

The samples were prepared by thermal evaporation method onto glass substrates by simultaneous evaporation of Gd and Fe from two different sources in a vacuum of 10^{-6} mbar. The boron-silicate glass substrates (Menzel glasses of 18 x 18 mm) were kept at room temperature. The deposition rate was about 1.5 Å/s. The film thicknesses and the compositions were determined and respectively evaluated using two independent quartz-crystal oscillators and special calibration. The composition of the deposited samples was additionally checked by scanning electron microscopy (SEM) with EDX using a JEOL- 60 kV microscope. The structure of the films was analyzed by X-ray diffraction using Cu K_α radiation.The film thicknesses were 700 Å for $Gd_{0.21}Fe_{0.79}$ and 900 Å for $Gd_{0.46}Fe_{0.54}$ films. Magnetic properties and magnetic anisotropy were studied by magneto-optical

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transversal Kerr effect method and by torque magnetometer in the same geometry as described by S. Chikazumi [9]. The magnetisation measurements were performed in a magneto-optical transversal Kerr effect installation developed in our laboratory. This allows the measurements to be taken inside the vacuum chamber in order to avoid the influence of the oxidation of the surface of the film as well as outside of the chamber [3]. Outside of the vacuum chamber, the optical system was mounted on an antivibrational table. We used a precise stabilized laser system with a very small spot size with a diameter of about 1.30 mm. An additional heat treatment of the samples was performed in a furnace at 350 ºC for 30 minutes in a high vacuum of about 10^{-6} mbar.

3. Results

The X-ray diffraction patterns show that both samples have an amorphous structure, as can be seen in Fig. 1 for the case of Gd-rich film.

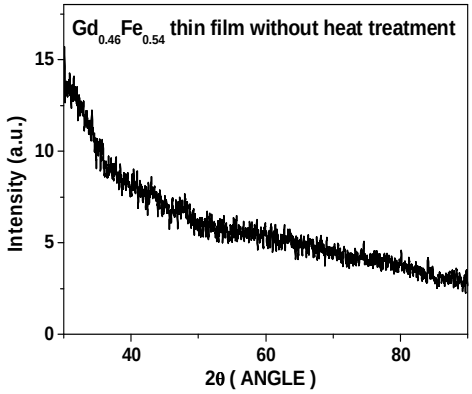

Fig. 1. X-ray diffraction for the 900 Å Gd-rich film deposited for deposition rate 1.5 Å/s onto boron-silicate glass substrate with no additional heat treatment.

Fig. 2 shows the hysteresis loops obtained outside of the vacuum chamber for both films. The inverted sense of the hysteresis loop corresponding to the $Gd_{0.46}Fe_{0.54}$ (RE dominated) film should indicate the ferrimagnetic character of the films. Also, the opposite senses of the hysteresis loops for both films show that their compositions are below (Fe-rich) and above (Gd-rich) the room temperature compensation composition (RTCC). The description of similar behaviour can be found in many publications (see, for example, [9]). For both types of samples, the measured coercivity at room temperature was about 20 Oe.

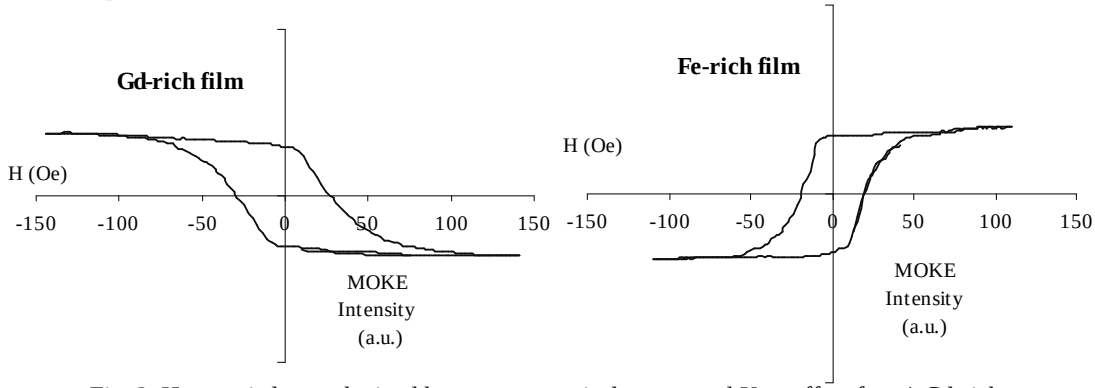

Fig. 2. Hysteresis loops obtained by magneto-optical transversal Kerr effect for: a) Gd-rich film; b) Fe-rich film

In order to study the anisotropy of the samples, torque magnetometry was used. The measurements were made in the temperature range from 77 to 330 K and in the interval of the magnetic fields from zero to 13 kOe, some of them are shown in Fig. 3. In the initial state, i.e. just

after deposition, both types of samples show typical in-plane magnetic anisotropy torque curves. The Fe-rich film magnetisation does not change over this temperature range, but Gd-rich film magnetisation shows a consistently slow decay as the temperature increases.

After that, the samples were annealed at 350ºC for 30 minutes in a furnace in a high vacuum of about 10^{-6} mbar to avoid, as far as possible, the surface oxidation during the heat treatment. The temperature dependency of magnetisation and the magnetic anisotropy of Fe-rich film do not change but the magnetisation value increases up to about 25% (Fig. 4). On the other hand, the magnetisation of Gd-rich film measured at room temperature decreases as a result of the annealing. The torque curves show, in this case, that the perpendicular magnetic anisotropy, PMA, becomes dominant at low temperatures, as can be seen in Fig. 3.

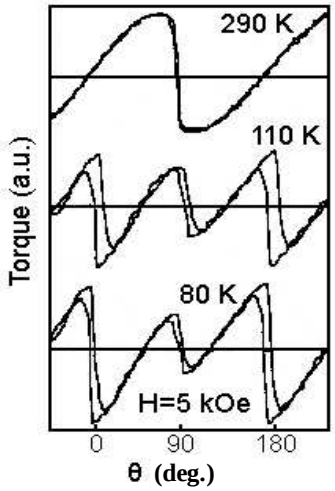

Fig. 3. The torque curves measured at different temperatures on Gd-rich $Gd_{0.46}Fe_{0.54}$ film after heat treatment at 350 °C for 30 minutes. θ is the angle between the plane of thin film sample and the direction of the external field.

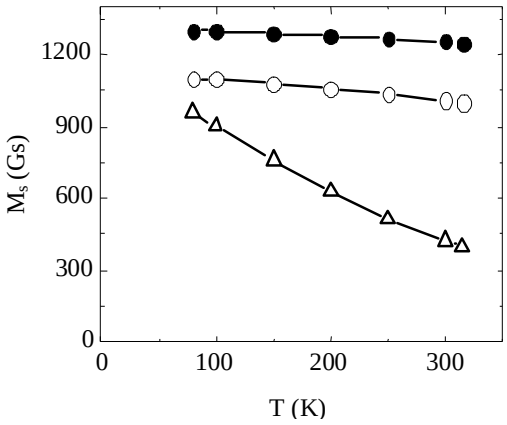

Fig. 4. The temperature dependence of the magnetisation for Fe-rich (○,●) and Gd-rich film (Δ): just after deposition (○, Δ) and after heat treatment in vacuum at 350ºC for 30 minutes (●).

4. Discussion

It was observed that just after deposition the Fe- rich composition is below the RTCC and the Gd–rich composition is above the RTCC, as the opposite sense of the hysteresis loops indicates (Fig. 2). This can be easily understood if the ferrimagnetic character of the magnetic state of the films is considered. After the annealing treatment, the hysteresis loops for the Gd-rich film has no inverted sense, which indicates that the composition for the Gd rich film is below the RTCC.

One may remember different suggested mechanisms of perpendicular magnetic anisotropy (anisotropic pair distribution with respect to the plain of the film or columnar structure). The single ion anisotropy, which may appear in RE metals due to spin-orbital interaction does not really work in the case of gadolinium with symmetric electron shells [7,10]. It is very probable that the partial oxidation of Gd play an important role in the formation of the effective anisotropy [11,12]; despite the fact that heat treatments were done in a high vacuum. The partial oxidation may appear from the substrate side because the presence of a small amount of oxygen attached to the substrate surface before the deposition. This would produce a reduction in the effective amount of magnetic part of Gd present in the film.

We suppose that in the case of Gd-rich film after the heat treatment it has a compensation temperature below 77 K. When the temperature decreases from room temperature, the magnetisation decreases, and therefore the shape anisotropy decreases. This results in the appearance of an effective PMA due to the domination of the perpendicular magnetic anisotropy over the shape anisotropy.

In order to understand and explain this difference, one should take into account the possible structural variations, and/or internal stress changes and magnetostriction influence. This last point is an important parameter in the case of very thin films deposited onto glass substrates having rather high roughness in comparison with polished Si substrates. The annealing may reduce the stress which appears in the zone close to glass/film surface. The heat treatment leads to relaxation in the case of a non-zero magnetostriction sample.

5. Conclusions

In conclusion, amorphous thin films with $Gd_{0.21}Fe_{0.79}$ and $Gd_{0.46}Fe_{0.54}$ compositions have been studied. It was observed that magnetisation increases for Fe–rich film and it decreases for Gd-rich film after annealing. Also, an effective PMA appears in the case of Gd rich film. Although the origin of the perpendicular magnetic anisotropy is not clarified, we have suggested that part of these phenomena can be explained by partial oxidation of the Gd during the heat treatment.

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