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Magnetic properties of thin film GdCoRe amorphous alloys

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Abstract

Thin film amorphous samples of $(Gd_{1-x}Co_x)_{1-y}Re_y$ (a-GdCoRe) have been grown using a RF sputtering system. In order to consider these ferrimagnetic a-GdCoRe alloys for application in bubble devices, we have studied the temperature dependence of the saturation magnetization (M_s) and coercivity (H_c) as a function of composition, in the concentration range $0.74<x<0.84$, $0.08<y<0.12$. From M_s vs. T plots, compensation temperatures (T_{comp}) have been determined for all samples. The temperature dependence of the coercivity (H_c vs. T) displays the sharp maximum at the compensation temperature (T_{comp}) that is characteristic of ferrimagnetic amorphous alloys. All the samples studied show perpendicular anisotropy. The effect of Re addition on the magnetic properties of a-GdCo alloys will be discussed in comparison to those of other elements, as Mo. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Amorphous materials; Magnetic films and multilayers; Thin films; Vapour deposition; Magnetic measurements

1. Introduction

Amorphous intermetallic films, such as a-GdCoMo, have been proposed as a possible alternative to crystalline for magnetic bubble devices [1,2]. The magnetization of these ferrimagnetic materials can be easily tuned over a wide range because it is the difference between the magnetization of the cobalt and gadolinium sublattices. They can be fabricated on inexpensive substrates (usually glass) and using different deposition techniques (e.g. evaporation, laser ablation, sputtering). Another advantage is their wider range of magnetic properties, in comparison with other alternatives, such as crystalline garnet films. The a-$Gd_{1-x}Co_x$ alloys [3] were the first amorphous systems discovered to be able of supporting bubbles in thin film form. As a matter of fact, this type of materials shows a combination of large enough anisotropy and M_s values that make them suitable to support smaller bubbles than, for example, those obtained in garnet films. However, for practical purposes M_s must be kept below certain values. To ensure the stability of the device, we need to get a fairly constant M_s vs. T curve, i.e. the working temperature (300 K) must be midway between the compensation temperature for the two subnetworks (T_{comp}) and the Curie temperature (T_c). This can be achieved by introducing a third non-magnetic element as dilutant. Usually this third element is a transition metal such as Mo, Cr, Cu or Au [1]. So far, the films with best properties are obtained using Mo. The aim of this work is to verify if amorphous $(Gd_{1-x}Co_x)_{1-y}Re_y$ thin films (a-GdCoRe) are also suitable for bubble devices and to compare their properties with those of a-GdCoMo.

2. Experimental

Amorphous thin films of $(Gd_{1-x}Co_x)_{1-y}Re_y$, were grown using a RF sputtering system. Samples were deposited on glass substrates at room temperature and without any bias voltage. The background pressure was about 6×10^{-7} mbar. Deposition was performed in 99.999% pure Ar, with a pressure of 3.3×10^{-3} mbar, at a fixed substrate-target distance of about 4 cm. Sample composition was tuned by attaching small pieces of Gd (99.9%) and Re (99.99%) to the pure Co (99.99%) target, and monitored using Energy dispersive X-ray microanalysis (EDAX). A typical amount of 2% Ar incorporated from the sputtering gas was detected in our samples. No evidence of significant oxygen contamination was found. For the samples studied in this work, Co concentration (x) was kept in the range $0.74<x<0.84$, whilst Re concentration (y) was varied in the interval $0.08<y<0.16$. Due to the critical dependence of the properties on the actual stoichiometry of the alloys, the composition was measured on several points of each sample. Conventional X-ray diffraction θ-2θ spectra using Cu K_α radiation revealed the amorphous character of the films (Fig. 1). The thickness of the samples, as determined

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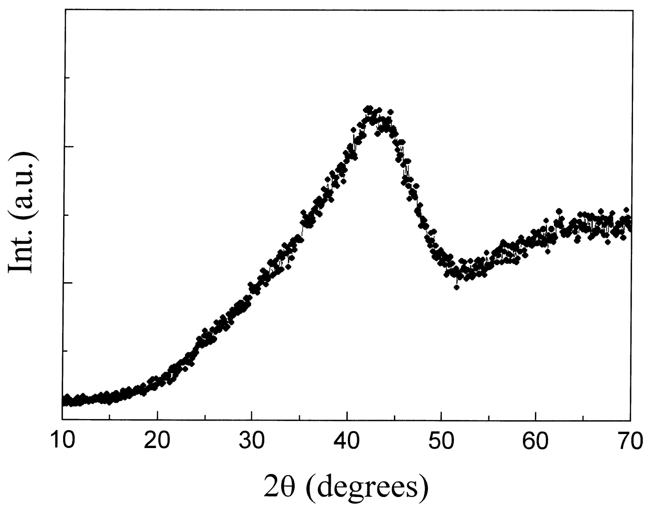

Fig. 1. X-ray diffraction pattern of a typical amorphous $(Gd_{1-x}Co_x)_{1-y}Re_y$ alloy film with $x=0.74$ and $y=0.08$, showing the amorphous character of the sample.

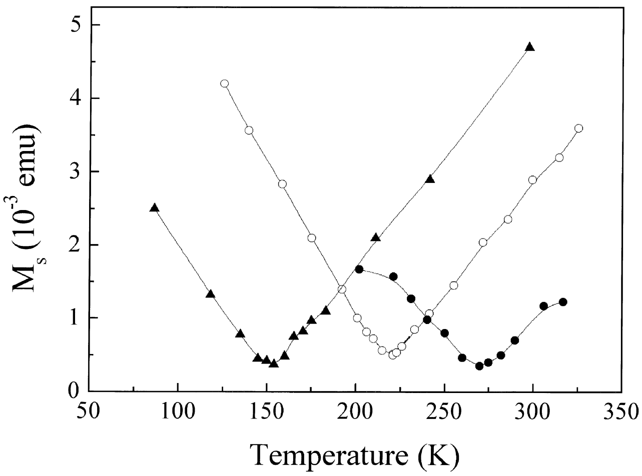

Fig. 3. M_s vs. T for $(Gd_{1-x}Co_x)_{1-y}Re_y$ for $x=0.80$ (●), 0.81 (○), 0.82 (▲), $y=0.09$. Measurements were performed in two extra samples that showed T_{comp} out of our range of measurement: $(Gd_{0.22}Co_{0.78})_{0.91}Re_{0.09}$ ($T_{comp}>320$ K) and $(Gd_{0.16}Co_{0.84})_{0.91}$ $Re_{0.09}$ ($T_{comp}<80$ K), as expected from the trend shown in this graph.

using scanning electron microscopy, was about 1 μm. Saturation magnetization (M_s) and coercivity (H_c) were simultaneously determined from hysteresis loops measured at different temperatures, using a vibrating sample magnetometer (VSM) with the magnetic field, up to 15 kOe, applied in the normal direction to the plane of the film.

3. Results

In Fig. 2 we present M_s and H_c vs. T for a sample showing a clear compensation temperature slightly below room temperature. The sharp maximum of H_c right at T_{comp}, typical of ferrimagnetic amorphous alloys [4], is apparent in this plot. In order to avoid experimental difficulties related to the sudden increase of coercivity close to T_{comp}, the magnitudes H_c and M_s were measured from hysteresis loops. T_{comp} was determined from plots of M_s vs. T. All the a-GdCoRe samples obtained using the deposition parameters indicated above, as well as other a-GdCo samples showing T_{comp} close to room temperature, displayed perpendicular anisotropy, with the easy axis of magnetization perpendicular to the film plane.

The results of M_s vs. T measurements for different samples with a fixed Re concentration $y \cong 0.09$ are displayed in Fig. 3. This plot shows how it is necessary to raise the Co/Gd proportion to keep T_{comp} around room temperature (~275 K). A similar conclusion can be inferred from the results shown in Fig. 4, which correspond to three samples with similar T_{comp} but different content of rhenium. As in the previous case, an increase of the Co/Gd ratio allows to compensate for the effect of progressive Re doping. That means that Re reduces the total moment of the cobalt sublattice. In agreement with

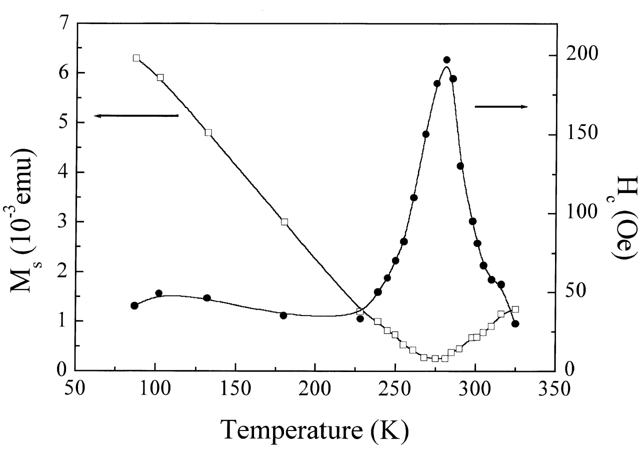

Fig. 2. Saturation magnetization (M_s) and coercivity (H_c) for $(Gd_{0.20}Co_{0.80})_{0.88}$ $Re_{0.12}$ with $T_{comp}=275$ K.

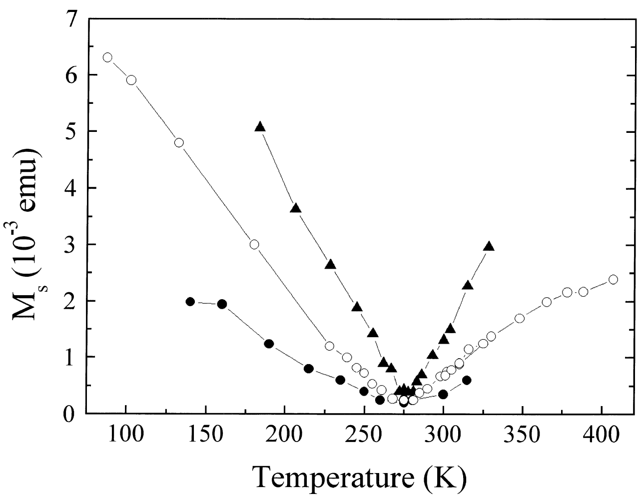

Fig. 4. M_s vs. T curves for the films $Gd_{22}Co_{78}$ (▲), $(Gd_{0.2}Co_{0.8})_{0.88}$ $Re_{0.12}$ (○) and $(Gd_{0.19}Co_{0.81})_{0.84}$ $Re_{0.16}$ (●).

this interpretation, Re dilution results also in a reduction of M_s in the whole temperature range, as it can be readily observed in the M_s vs. T curve. As we have already pointed out in the introduction, this additional effect is a desirable result from the technological point of view.

4. Discussion

From the results presented in Figs. 3 and 4, it is readily concluded that the effect of Re dilution on the compensation temperature of GdCo is similar to that of Mo. For comparison, $T_{comp}=270$ K was reported for a sample of $(Gd_{0.16}Co_{0.84})_{0.84}Mo_{0.16}$ [1], whilst for the equivalent composition $(Gd_{0.16}Co_{0.84})_{0.84}Re_{0.16}$ we have obtained T_{comp}~200 K. As expected, higher concentrations of Re can be used to raise T_{comp} above the latter value, in excess of room temperature for $y=0.2$ (not shown). We want to point out that in $Gd_{0.16}Co_{0.84}$ the moment of the cobalt sublattice overcomes that of the Gd one, so there is not a compensation temperature for this particular composition. Thus, Re has indeed a destructive effect on the Co moments, although in a lesser degree than Mo does.

It has been proposed [1,5,6] that the result of diluting a third element in the system Gd–Co can be understood in terms of two competing effects: (i) electronic transfer from the dopant to the conduction band of Co, that lowers the Co moment and (ii) weakening of the exchange coupling that reduces the Gd sublattice moment. To illustrate on the relevance of the electronic transfer effect, it is worth to remind that even in absence of a third dopant element, the electronic affinity of Co results in the transference of about 1 electron from the Gadolinium atom [6]. In the case of Rhenium, that due to its electronic structure could donate up to seven electrons to Cobalt, two more than Mo, an explanation of our results in terms of electronic transfer is also appropriate. However, as we have already explained, the effect of rhenium doping on T_{comp} is less dramatic than that of molibdenum, maybe due to the slightly more electronegative character of Re respect to Mo (+1.9 vs. +1.8). When compared with other dopants (Au, Cr, and Cu) [1,7], rhenium results to be more effective on raising T. On the other hand, a non-magnetic dilutant is expected to depress the already somewhat weakened exchange interaction between Gd moments. Due to the similar size of Re and Mo atoms (0.137 nm and 0.139 nm) we do not expect this last effect to be more important for a-GdCoRe than for a-GdCoMo. In summary, we think that our results can be explained in terms of electron transfer from the Re atoms to the cobalt sublattice.

5. Conclusions

Amorphous $(Gd_{1-x}Co_x)_{1-y}Re_y$ films showing perpendicular anisotropy have been obtained using rf sputtering. The effect of Re dilution on the magnetic properties of a-GdCo alloys is similar to that reported for Mo. In particular, the compensation temperature is significantly raised upon progressive Re doping. This effect can be explained in terms of electron transfer from Re atoms to the conduction band of Co. Thus, a-GdCoRe films present magnetic properties similar to those of a-GdCoMo, which, in principle, would make them suitable for magnetic bubble devices.

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