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Amorphous Metallic Films for Bubble Domain Applications

Abstract: We have found that sputtered amorphous films of Gd-Co and Gd-Fe have perpendicular magnetic anisotropy. The demagnetized domain configuration consists of stripe domains, and bubble domains were nucleated in an applied field. By controlling the sputtering conditions, films with a wide variety of magnetic properties were obtained.

Introduction

Materials which are atomically disordered but magnetically ordered have been known for a number of years. Materials in this class include evaporated thin films [1-3], splat cooled alloys [4], and electrochemically deposited films [5]. We have prepared magnetically ordered amorphous films of Gd-Co and Gd-Fe alloys by sputtering. Recently, amorphous films of $TbFe_2$ have also been prepared by sputtering and have been shown by neutron diffraction [6] to be magnetically ordered.

We have studied the domain structure of our amorphous sputtered films of Gd-Co and Gd-Fe by means of Lorentz microscopy, Bitter patterns, and Kerr contrast and find that under certain conditions of fabrication the demagnetized domain configuration consists of stripe domains. It has also been found that bubble domains can be nucleated in an appropriate applied field. Both states are shown in Fig. 1. These results have led us to examine the potential utility of amorphous materials for bubble domain device application. Indeed we have built and operated shift registers on these materials. The material used in the shift registers had a bubble diameter of 2 μm. Bubble generation, propagation, cornering and annihilation were achieved.

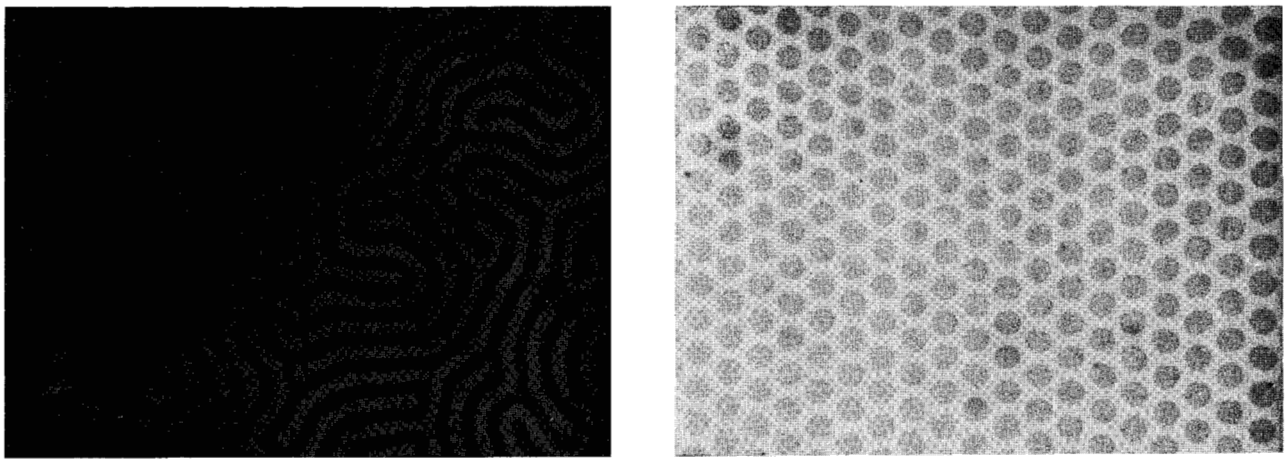
In this note we summarize some of our results on the method of fabrication of these films, their structure and composition, and such magnetic properties as saturation magnetization, coercivity, and anisotropy.

Experimental Results

The Gd-Co and Gd-Fe films were prepared by sputtering. Both rf and dc sputtering were used. The targets were fabricated by arc melting mixtures of the elements. Upon applying a negative bias voltage to the substrates during sputtering, the composition of the film was varied by as much as 10 atomic percent over the nominal composition expected from a given target. Films with a wide range of compositions were prepared and their properties investigated. The deposition was carried out on a variety of substrates, which included amorphous materials such as glass and fused quartz, polycrystalline materials such as copper and tungsten, and single crystal substrates such as NaCl, Al_2O_3, Si, and mica. In addition, flexible substrates such as heat stable polymers were also used. In order to provide good heat transfer the substrates were gallium backed and mounted on a water cooled molybdenum block. The temperature of the substrates at the start of deposition was near room temperature. Most of the results reported here were obtained on glass substrates. However, the properties of these films were found to be essentially independent of the nature of the substrate.

The structure of the as-deposited films was investigated by transmission electron microscopy and by reflection electron diffraction. The films were found to be amorphous and the diffraction patterns showed characteristic broad halos. High resolution dark field electron microscopy showed the films to have coherently scattering regions less than 25 Å in diameter.

The average compositions of the films were determined by x-ray fluorescence analysis. Composition (and impurity content) fluctuations in the thin films as a function of film thickness were determined by α-backscattering. Similar investigations of fluctuations parallel to the plane of the film were carried out with a microprobe.



(a) (b)

Figure 1 (a) Stripe domains in a Gd-Co alloy. Kerr contrast; magnification 500×. (b) Bubble domains in a Gd-Co alloy. Kerr contrast; magnification 500×.

Within the resolution limit of the techniques the ratio of Gd to Co was found to be independent of spatial position in the film.

The room temperature magnetization was determined either directly on a force balance or indirectly from bubble statics. The saturation magnetization, $4\pi M_s$, is shown as a function of the film composition in Fig. 2. The solid line (as explained later) gives the calculated values. The moment goes through a minimum at approximately 78 at. % Co. We note that the value of $4\pi M_s$ goes from a few hundred to several thousand Gauss when the Gd to Co ratio is varied from the minimum.

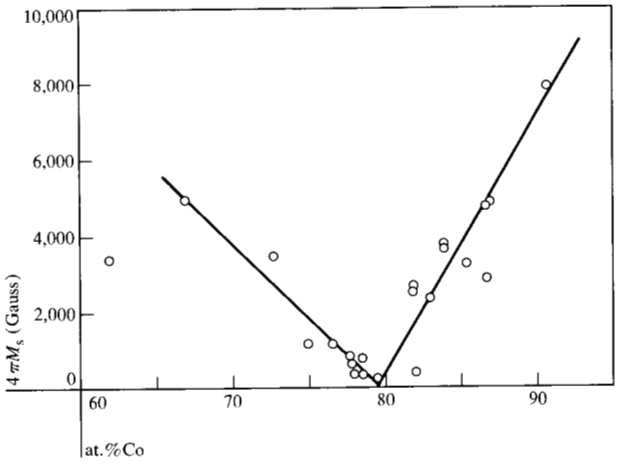
The variation of saturation magnetization with composition can be explained, as in the case of the Gd-Fe system [3], by antiferromagnetic coupling between the Gd and Co atoms. This assumption explains the presence of the minimum. The solid lines shown in Fig. 2 were calculated on this basis.

The fundamental length, l, is defined by [7]

$$l = \frac{\sigma_w}{4\pi M_s^2} = \frac{(AK_u)^{\frac{1}{2}}}{\pi M_s^2}, \qquad (1)$$

where σ_w is the wall energy, A the exchange constant, and K_u the anisotropy energy. The value of l was obtained from strip width and film thickness measurements [8]. In general l^{-1} varied approximately with composition, as did the square of the magnetization. This is suggested by Eq. (1) if σ_w is assumed to be constant. However, we observed considerable scatter in the data which, we propose, is associated with a variation in σ_w with film deposition conditions. This can be demonstrated by plotting $l \times 4\pi M_s^2$ as a function of bias voltage, as shown in Fig. 3. With increasing bias the value of σ_w increases. Apart from the effect of bias voltage there is

Figure 2 Room temperature saturation magnetization as a function of film composition in Gd-Co alloys.



also a thickness effect on the magnetic properties. We show, for example, in Fig. 4 the variation in l as a function of thickness for a Gd-Fe film sputtered from a selected target. When the thickness is less than 2000 Å only in-plane magnetization is observed. Above 2000Å perpendicular anistropy is observed and the value of l reaches a limiting value. Similar curves are obtained for other bias voltages and compositions not only for the Gd-Fe alloys but also for the Gd-Co alloys.

The anisotropy constant K_u was determined by ferromagnetic resonance and in the case of the Gd-Co alloys typical values of Q ($\equiv K_u/2\pi M_s^2$) were well in excess of one. The diffraction data suggest that the extent of atomic order in these alloys is less than 25 Å. Beyond this distance (and certainly within the range of thickness

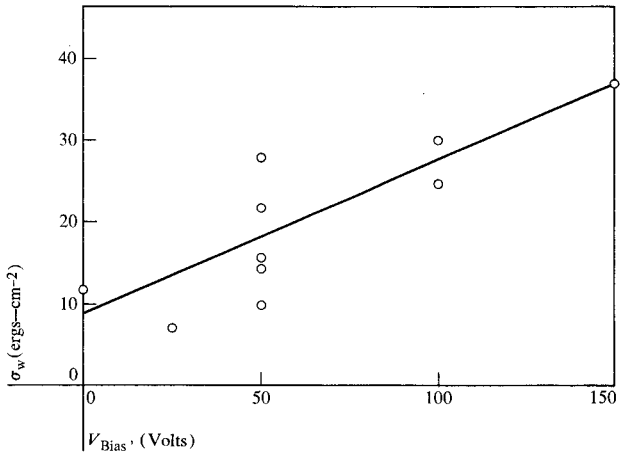
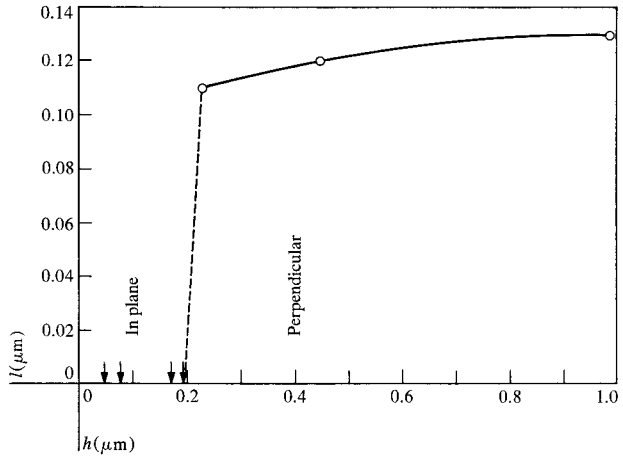


Figure 3 The effect of applied bias voltage on the domain wall energy for Gd-Co films.

Figure 4 Dependence of characteristic length l on film thickness in a Gd-Fe film. To the left of the dashed line the magnetization was in plane.



of typical films) we expect, and the diffraction data confirm, no long range order. Magnetocrystalline anisotropy therefore cannot give rise to the observed perpendicular component.

Stress induced anisotropy is not considered to be significant in these films. A film grown on a NaCl substrate showed no substantial change in domain strip width before and after the substrate had been dissolved in water. Had stress been a significant factor the magnetization – in particular the perpendicular component – would have shown large changes when the film was no longer constrained and therefore no longer stressed by the substrate.

Pair ordering and shape anisotropy are the two remaining possibilities. We suggest that both of these contribute to the anisotropy. The details of these processes will be described in a later publication.

Finally we consider the question of coercivity. For bubble domain applications a preferred upper limit of coercivity is one percent of the saturation magnetization [7]. Measurements on the Gd-Co alloys using the bubble run-out technique have yielded values from one-half to a few percent of the saturation magnetization. The relatively low value of coercivity can be qualitatively explained on the basis that the domain wall width is substantially larger than the coherently scattering regions. As a result the wall rides on a higher but essentially uniform potential.

Conclusion

The amorphous rare earth-transition metal alloys show potential as a new class of bubble domain materials. Because the rare-earth and the transition-metal moments are opposed in these materials, it is possible to find compositions with low values of $4\pi M_s$. Anisotropy sufficient to stabilize perpendicular domains can be induced by appropriate fabrication techniques, and the induced anisotropy is relatively insensitive to the substrate. The materials are easy to fabricate by conventional thin film methods and their properties can be varied over a wide range simply by varying the rare earth-transition metal ratio.

Acknowledgments

The authors are grateful to many colleagues in this laboratory for useful discussions. They also acknowledge the helpful assistance of several laboratory personnel and their facilities. In particular, they would like to thank B. E. Argyle, F. Cardone, B. Chider, D. Cronemeyer, S. Herd, H. L. Hu, W. Kateley, H. Lilienthal, T. McGuire and W. Molzen for such assistance, and J. Powers, P. Roland, V. Sadagopan and J. Ziegler for supplying information prior to the publication of data.

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Received November 22, 1972

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