Journal of Alloys and Compounds 267 (1998) L9–L11

Letter

Anomalous magnetic behaviour Of $(Tb_{0.27}Dy_{0.73})_{0.32}Fe_{0.68}$ amorphous thin film

Ch.V. Mohan*, H. Kronmüller

Max-Planck Institut für Metallforschung, Institut für Physik, Heisenbergstrasse 1, D-70569 Stuttgart, Germany

Received 2 September 1997

Abstract

Very high coercive fields have been observed at low temperatures in an amorphous $(Tb_{0.27}Dy_{0.73})_{0.32}Fe_{0.68}$ sputter deposited thin film. Coercive field data are presented for films of different thickness. A very sharp decrease of the coercive field, similar to that in 'bulk' amorphous $REFe_2$ (RE=rare earth), has been observed. The time effect on the remanent magnetisation has also been measured which is similar to that of superparamagnetic particles. The large values and the drastic temperature variation of the coercive field is very well explained by the partial breaking up of the long range magnetic order due to the presence of RE spins distributed randomly in the amorphous matrix. © 1998 Elsevier Science S.A.

Keywords: Amorphous thin film; Sputtering; Large coercivity

There have been numerous reports on the magnetic properties of various types of amorphous thin films and thin film multilayers. However, not much of efforts have been devoted on the coercivity of these systems which is precisely the reason why the coercivity mechanisms in thin films and their multlayers are not well understood. Thin films based on Rare earth (RE) and transition metal (TM) elements have been attractive materials for magneto-optic recording purposes [1–4] and magnetostrictive devices. It is very important to understand the coercivity mechanisms in these samples as the coercivity governs the domain size, shape etc. Any inhomogeneities in the domain sizes are caused by the fluctuations in the coercivity. We have taken up a program in our laboratory to study the coercivity mechanisms in various types of thin films and thin film multilayers. As a part of this work, we present some of our results in this letter.

Thin films of composition $(Tb_{0.27}Dy_{0.73})_{0.32}Fe_{0.68}$ have been prepared using the rf-sputtering method under Ar gas. These films have been deposited on Si substrates. We have chosen samples of four different thickness values of about 1500, 2000, 2500 and 3000 Å. The idea behind choosing various thicknesses is to make a detailed study of the anisotropy constants involving a systematic study of the temperature and thickness dependence of the anisotropy constants and to see a continuous transformation of the surface anisotropy values to their bulk values. However, these results will be published elsewhere [5] since the aim of the present letter is to highlight the coercivity behaviour.

The magnetisation measurements have been performed on these samples using a SQUID magnetometer (model: MPMS) with the applied magnetic directed along the film plane after the amorphous nature of the samples is verified with the help of the X-ray diffraction experiments [6,7]. The Curie temperatures of these samples match very well with the values reported by the earlier investigations. The magnetisation values per sample (instead of magnetisation per unit mass) are given because of the fact that it is difficult to measure the density of the sample in the thin film form and estimation of the sample weight by using 'bulk' density may lead to serious errors in the magnetic moment value even if there is only a slight difference between the density values of the thin films and the bulk form and also because of the errors in the estimation of the exact thickness.

We present the magnetisation isotherms corresponding to the sample with a thickness of about 3000 Å recorded in the temperature range 5–400 K in Fig. 1. Fig. 1(a) presents the data for temperatures below 100 K and Fig. 1(b) presents magnetisation data in the temperature range 100–400 K. Though the magnetisation data for temperatures

---

*Corresponding author. Presently at: Max-Planck Institut für Mikrostrukturphysik, Weinberg 2, D-06120 Halle, Germany.

0925-8388/98/$19.00
PII S0925-8388(97)00524-0

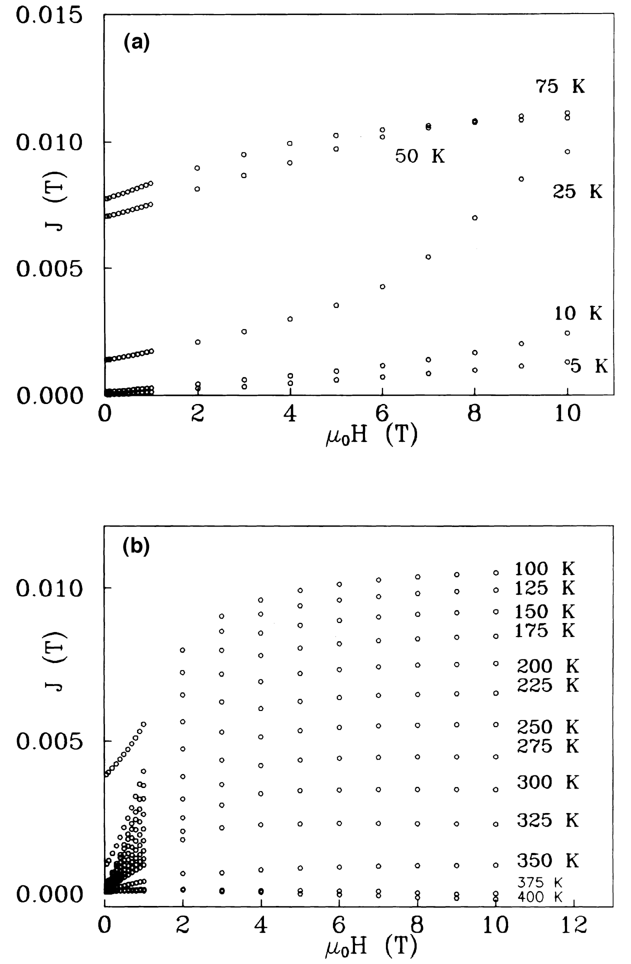

Fig. 1. Magnetisation isotherms recorded on amorphous $(Tb_{0.27}Dy_{0.73})_{0.32}Fe_{0.68}$ thin film (about 3000 Å thickness) at various temperature values (a) below 100 K and (b) between 100 and 400 K.

above 100 K represent conventional ferrimagnetic behaviour, below this temperature the data present the development of an anomalous ‘coercive field’ like behaviour. The significant high field susceptibility indicates that the spins in the system are somewhat loosely coupled among which some RE spins are not fully aligned in zero-field due to the random anisotropy field brought about by the amorphous structure i.e., structural disorder.

The kink point measurements performed on the sample with thickness about 3000 Å are shown in Fig. 2. The Curie temperature value is considerably lower to that of its crystalline counterpart and is characteristic of the amorphous nature.

The hysteresis loop measured at 5 K on the sample with thickness about 3000 Å is shown in Fig. 3. This curve shows a large value of the coercive field. Similar values were already observed in ‘bulk’ amorphous $REFe_2$ (RE= Dy and Tb) alloys [8,9]. This letter reports values of H_C in amorphous $(Tb_{0.27}Dy_{0.73})_{0.32}Fe_{0.68}$ thin films which are slightly higher as compared to the values of bulk samples of $TbFe_2$ and $DyFe_2$. The values of the coercive field

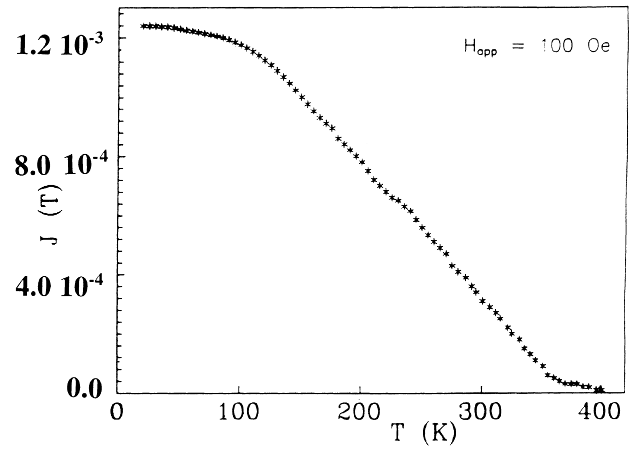

Fig. 2. Kink point measurements performed on amorphous $(Tb_{0.27}Dy_{0.73})$ $0.32Fe_{0.68}$ thin film (3000 Å thickness) in the presence of an applied magnetic field of 100 Oe.

closely correspond to the values required to reach the technical saturation in the virgin curves. We have also measured the temperature dependence of this coercive field and these data are shown in Fig. 4.

It is very interesting to see such anomalously high coercive fields and their extreme temperature dependence, especially considering the fact that much of the increased effect takes place for temperatures below 50 K at which both the magnetisation and anisotropy energy are saturated. The steep fall in the coercivity values with increasing temperatures represents a type of thermal activation process and could be explained based on the model for a non-collective spin transition which depends on the random distribution of spin moments of the rare-earth material in the loosely coupled amorphous matrix [9]. In other words, the magnetic free energy of each spin will differ since the local anisotropy and local exchange fields are different. This energy distribution will have two minima when the anisotropy energy has a magnitude of the order

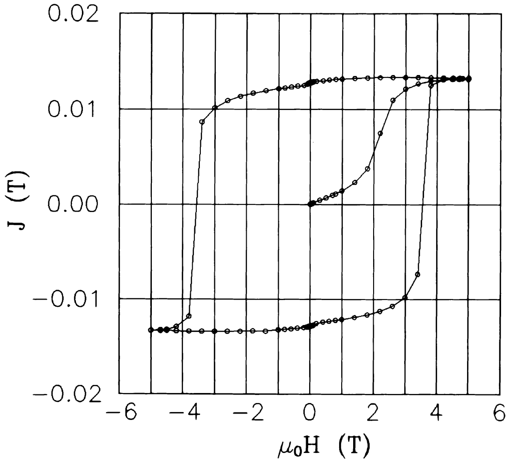

Fig. 3. Hysteresis loop measurements performed on amorphous $(Tb_{0.27}Dy_{0.73})_{0.32}Fe_{0.68}$ thin film (3000 Å thickness) at 5 K.

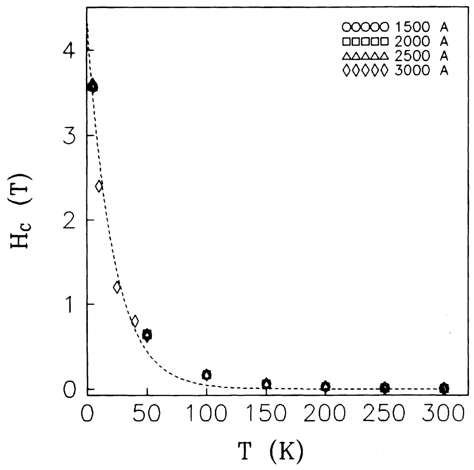

Fig. 4. Temperature dependence of coercive field in $(Tb_{0.27}Dy_{0.73})_{0.32}Fe_{0.68}$ amorphous thin films.

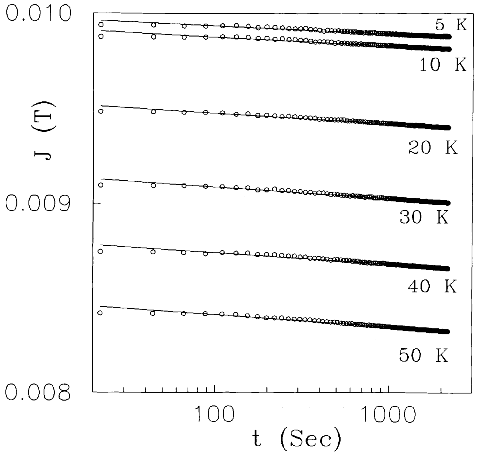

Fig. 5. Time variation of the remanent magnetisation at low temperatures for amorphous $(Tb_{0.27}Dy_{0.73})_{0.32}Fe_{0.68}$ thin film (3000 Å thickness).

of the applied field and exchange energies and the moment of a spin or group of spins will involve a discontinuous flip which is the most favourable energy state under the influence of a proper applied magnetic field which would alter the local exchange field and this process goes on. If the thermal energy is comparable with the energy barrier between the minima, a sharp temperature dependence of the coercive field can occur which is precisely what we observe in Fig. 4. The results on the 'bulk' amorphous samples have also been explained under similar lines using this model based on thermally activated processes. A more detailed report on the temperature dependence of the coercive field including for temperatures below 5 K along with the calculation of the anisotropy field will be published elsewhere [5].

We have also measured the time variation of the remanent magnetisation for few temperatures much below the Curie temperature (Fig. 5). A slow decrease of the remanent magnetisation has been observed with increasing time which can not be attributed to the kink criterion since the coercivity is not of intrinsic origin and could only be attributed to the characteristics of the spin systems with superparamagnetic particles. Similar observations were made earlier on 'bulk' amorphous samples of $TbFe_2$ and $DyFe_2$ alloys [8].

In conclusion, we have observed very high coercive fields in thin films of amorphous $(Tb_{0.27}Dy_{0.73})_{0.32}Fe_{0.68}$ alloy which are slightly higher compared to those for 'bulk' amorphous $TbFe_2$ and $DyFe_2$ alloys and could be attributed to a different amorphous structure in thin-film form. However, the origin of this coercivity could qualitatively be explained based on similar lines as in bulk samples.

The authors wish to acknowledge Mr. B.Ludesher for his help in the preparation of the samples. One of the authors (ChVM) also thanks the Max-Planck society for financial assistance.

References

[1] W.B. Zeper, F. Greidanus, P.F. Garcia, IEEE Trans. Magn. MAG-25 (1989) 3764.
[2] S. Hashimoto, Y. Ochiai, K. Aso, J. Appl. Phys. 28 (1989) L1824.
[3] C.J. Lin, H.V. Do, IEEE Trans. Magn. MAG-26 (1990) 1700.
[4] P.F. Garcia, W.B. Zeper, F.J.A.M. Greidanus, MRS Proceedings 150 (1989) 115.
[5] Mohan, Ch.V., Kronmüller, H., unpublished results, 1997.
[6] Schnell, M., Ph.D. Thesis, University of Stuttgart, Germany, 1996, unpublished.
[7] Winzek, B., Diploma thesis, University of Stuttgart, Germany, 1996, unpublished.
[8] A.E. Clark, Appl. Phys. Lett. 23 (1973) 642.
[9] J.J. Rhyne, J.H. Schelleng, N.C. Koon, Phys. Rev. B. 10 (1974) 4672.