Magnetic studies of amorphous Fe-Dy-B ribbons

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We have studied the magnetization of melt spun amorphous $Fe_{80-x}Dy_xB_{20}$ alloys with $0 \leq x \leq 7.5$ under magnetic fields up to $6T$, and have analyzed the results at 4.2 K on the basis of the random magnetic anisotropy model. Exchange constant and local random anisotropy K_L were evaluated. Using the Sarkisś model, the local anisotropies per atom are found to be 1.75 10^7 and 4 107 erg/cm^3 for Fe and Dy, respectively.

Keywords: Amorphous ribbons; Magnetization; Local random anisotropy

I. INTRODUCTION

Amorphous alloys based on rare-earth (R), transition metal (T) and metalloid (M) elements, such as T-R and T-R-M, show interesting magnetic properties and have been studied in the past by a number of authors [1–3]. As usually observed in the intermetallics, the magnetic moment of the heavy rare-earth in amorphous alloys couples antiferromagnetically to that of the transition metal. One of the fascinating behaviors in such amorphous alloys arises from the random magnetic anisotropy (RMA) which results from the topological disorder present in these materials. Indeed, Harris, Plischke and Zuckermann have first introduced the random axial anisotropy model for amorphous alloys by adding to the exchange interaction term, a single ion magnetic anisotropy term with different randomly-oriented directions at each site [4] Rare-earth metal atoms with an orbital moment are thus well known to give rise to large random anisotropy in amorphous alloys [4]. Some theoretical models have been developed to calculate the random anisotropy and related parameters from the analysis of the approach to magnetic saturation [5, 6]. In this work, we describe magnetic studies performed on amorphous $Fe_{80-x}Dy_xB_{20}$ alloys prepared by conventional melt-spinning technique and the results are discussed on the basis of the RMA model.

II. EXPERIMENTAL METHODS

Amorphous $Fe_{80-x}Dy_xB_{20}$ ribbons with $0 \leq x \leq 7.5$, were quenched in an inert atmosphere of Ar using the melt-spinning technique. The melt-spun ribbon were about 30 m thick with different widths varying from about 3 to 5 mm. X-ray diffraction was used to check the amorphous structure. The exact chemical composition of the samples was determined by electron probe microanalysis. The magnetization was measured in applied fields up to 6 T (in SNCI Grenoble) at 4.2 K. The Curie temperature TC was measured under a small applied field of 100 Oe.

III. RESULTS AND DISCUSSION

The field dependence of magnetization M shows that saturation is attained only for H of about 2 Tesla at 4.2 K. Fig.1 shows some typical results at 4.2K. The magnetization decreases with addition of Dy. This decrease in M clearly arises from the antiferromagnetic coupling between Fe and Dy moments. Though the addition of rare earth atom leads to decrease in the transition metal moment due to hybridization effects. The TC decreased from 660 to 530K when x increased from 0 to 7.5. The variation of the Curie temperature with x is also somewhat similar to that of the magnetization.

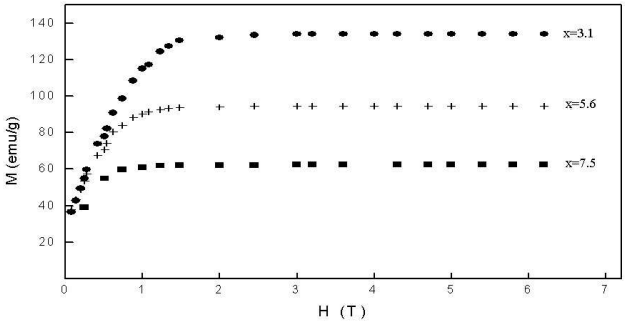

FIG. 1: The field dependence of magnetization at 4.2 K

The approach to saturation in the magnetization can be described in the following two ways according to Chudnovsky et al. [6–8]. For applied fields higher than the exchange field $H > H_{ex}$, the field dependence is expected to follow an H_{-2} law, whereas when $H < H_{ex}$, which incidentally is appropriate to our study, the dependence is best described by an $H^{-1/2}$ law. Therefore, in the latter case if one plots M as a function of $H^{-1/2}$, a linear dependence will be obtained and one can then write;

$$(M_0 - M)/M = (H_S/H)^{1/2}/15, \qquad (1)$$

where

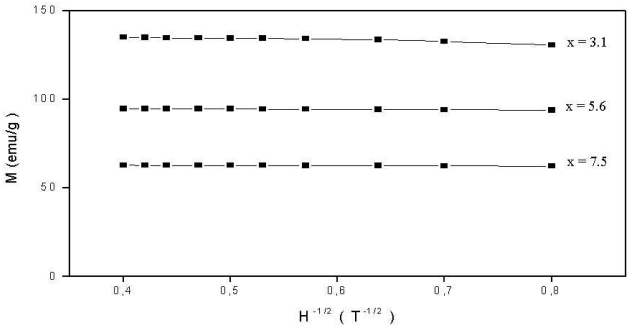

FIG. 2: The $H^{-1/2}$ dependence of the magnetization M at 4.2K

$$H_S = H_r 4/H_{ex}^3. \quad (2)$$

The exchange field Hex can also be expressed as

$$H_{ex} = 2A/M_0 R_a^2, \quad (3)$$

where R_a is the length over which the local anisotropy axes show a correlation (short-range structural order) [9, 10]. We assume R=10 A, as determined experimentally on similar alloys. The exchange constant A follows from the relation [11]:

$$A = CS_{Fe}k_B T_C/4(1+S_{Fe})r_{FeFe}, \quad (4)$$

where C is the iron concentration, S_Fe is the Fe spin, and rFeFe, the interatomic Fe-Fe distance, is taken as 2.5 A. We found that the exchange constant decrease from 36.4 10^8 to 24.6 10^8 erg/cm when x is increased from 0 to 7.5. M_0 is the saturation magnetization and Hr the random local anisotropy field. They are related to the local anisotropy energy K_L by the relation

$$H_r = 2K_L/M_0. \quad (5)$$

Fig. 2 shows the $H^{-1/2}$ dependence of M for $0 \leq x \leq 7.5$ at 4.2 K. Table I shows the various parameters obtained from the analysis of the data using the models described above.

The values of K_L deduced from the Chudnovsky's model are in the range 1.4 to 1.6 10^7 erg/cm^3, which are about ten times higher than normal values for anisotropy in crystalline transition metals. The random local anisotropy of amorphous $Fe_{80-x}Dy_xB_{20}$ alloys is higher than that found for amorphous $Fe_{80-x}Tm_xB_{20}$ alloys [12], which indicates that the contribution to the anisotropy from Tm is weaker than that from Dy. An increased anisotropy might result from the low symmetry of the atomic sites in the amorphous structure. In our case, we have the contribution of two sub-networks at the magnetic anisotropy in one hand the Dy which is a rare earth possessing an important magnetic anisotropy, and on the other hand the Fe for which the mean magnetic momentum is lower than that of the metallic counterpart. This situation shows that the Fe orbital momentum is incompletely quenched in the alloy, then we will find a spin-orbit interaction which will give rise to a local magnetic anisotropy in the Fe sub-network [13]. Finally the magnetic random local anisotropy constant evaluated by A. Sarkis [14] is a function of the inter-sublattice exchange interactions (n_{DyFe}= 61T/B evaluated by fitting of M-T curves [15]) and the sub-networks local anisotropies. The Sarkiss model gives us an effective anisotropy constant by

$$K_{eff} = K_L = [K_{Fe} + K_{Dy} + (2K_{Dy}K_{Fe}/n_{DyFe}M_{Dy}M_{Fe})]/[1 + 2(K_{Fe}M_{Fe}^2 + K_{Dy}M_{Dy}^2)/n_{DyFe}M_{Dy}M_{Fe}M^2] \quad (6)$$

To apply this model to the amorphous ribbons we consider that the sublattice anisotropy constants found in formula (7) are per the contents in the alloy. Thus for the transition metal we can write the anisotropy constant as $K_{Fe} = [(80-x)/100]K_{Fe}^{atom}$ where K_{Fe}^{atom} is the local anisotropy constant per atom for the Fe, we follow the same way with the rare earth constant. The local anisotropies per atom are found to be 1.75 10^7 and 4 10^7 erg/cm^3 for Fe and Dy, respectively. The values for K_{Fe}^{atom} deduced by us are in agreement with the values of the local magnetic anisotropy calculated by Fahnle using a semi-empirical Hartree-Fock perturbation approach for the local spin-orbit coupling operator [16]. It is known that the magnetic behavior of the random anisotropy system changes drastically with the value of the dimensionless parameter λ.

$$\lambda = (2/15)^{1/2}(R_a^2 K_L/A)R_a^2 \quad (7)$$

We found that λ is less than unit in our alloys (Table I), that suggest a ferrimagnetic system with weak anisotropy.

IV. CONCLUSION

In conclusion, we have prepared amorphous $Fe_{80-x}Dy_xB_{20}$ alloys and carried out magnetization studies. It was found that when the Dy content increases the magnetization and the Curie temperature

TABLE I: Some magnetic parameters of $Fe_{80-x}Dy_xB_{20}$ alloys at 4.2 K.

x	M0 (emu/g)	A (10^-8 erg/cm^3)	K_L (10^7 erg/cm^3)	λ
0.0	185	36.4	1.4	0.15
3.1	125	31.4	1.6	0.19
5.6	90	27.0	1.4	0.19
7.5	60	24.6	1.5	0.21

decrease. The random local anisotropy is close to 1.5 10^7 erg/cm^3. The exchange field is higher than that of the random anisotropy field, which corresponds to a ferrimagnetic system with weak anisotropy

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