Magnetization studies in amorphous $Co_{80-x}Gd_xB_{20}$

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We have studied amorphous $Co_{80-x}Gd_xB_{20}$ alloys prepared by melt spinning technique. The Gd moment at 4.2 K is found to be 7 μ_B which agrees with the theoretical value indicating a collinear spin structure. The magnetic compensation at 4.2 K occurs for x close to 10.3. The mean-field theory has been used to explain the temperature dependence of the magnetization. The exchange interactions between Co-Co and Co-Gd atom pairs have also been evaluated.

I. INTRODUCTION

Amorphous alloys based on rare earths (R) and transition metals (T) and metalloids (B), such as T-R and T-R-B, show interesting magnetic properties and have been studied in the past by a number of authors [see 1-3]. These materials offer the possibility to study various aspects of amorphous magnetism, such as, random anisotopy, nature of magnetic interactions, the dilution of magnetic moments. In contrary to crystalline materials these aspects can be investigated in a continuous concentration range of the rare-earth metal as well as in relation with the low local symmetry that is characteristic for the amorphous state. Rare-earth metal atoms with an orbital moment are known to give rise to large random anisotropy in amorphous alloys [4]. In the case of Gd amorphous alloys the random magnetic anisotropy effects are negligible due to the non-existence of an orbital moment of the Gd atom.

In order to study the influence of the addition of Gd on the various magnetic properties of amorphous Co-B alloys, we prepared amorphous $Co_{80-x}Gd_xB_{20}$ alloys with $0 \leq x \leq 14$ and investigated their magnetic properties. We have analyzed the thermal variation of magnetization in terms of the mean field theory.

II. EXPERIMENTAL

Amorphous $Co_{80-x}Gd_xB_{20}$ ribbons with $0 \leq x \leq 14$, were obtained in an inert atmosphere of Ar by melt spinning technique. The purity of the starting materials was 99.99 % for B, Gd, and 99.999 % for Fe. Argon ejection pressure of 2 to 5 kPa and a substrate speed of 35 m/s were employed. The melt ejecting tubes were made of quartz glass with an ejecting orifice of about 0.4 mm in diameter. The ribbon samples were about 30 μm thick with different widths varying from about 2 to 4 mm. The x-ray diffraction (XRD) measurements were performed at room temperature by using CoKα radiation. All samples were examined by XRD and were found to be amorphous. The exact chemical composition of the samples was determined by electron probe microanalysis. The magnetization was measured by vibrating sample magnetometer (VSM) from 4.2 to 300 K in magnetic fields up to 18 kOe. Curie temperature was determined using a VSM from 300 to 900 K in a small magnetic field of about 100 Oe.

III. RESULTS AND DISCUSSION

The technical saturation is attained for H < 5 kOe at all temperatures. Let us first discuss the results at 4.2 K. The alloy magnetic moment (expressed in Bohr magnetons μ_B) decreases with the addition of Gd which indicates the antiparallel coupling between the Co and Gd moments. It is known that the Co moment (μ_{Co}) diminishes when it is alloyed with a rare-earth metal due to 3d-5d hybridization, but this effect is negligible for small concentrations. So we took $\mu_{Co} = 1.25\ \mu_B$ obtained for the alloy with x = 0, and assumed this to be the same in the alloy with $x \leq 8$. Knowing the alloy moment (μ_a) and using the relation,

$$\mu_a = |\,(80-x)\ \mu_{Co} - x\ \mu_{Gd}\,| / 100 \qquad (1)$$

we find that $\mu_{Gd} = 7\ \mu_B$ in agreement with the theoretical value. This indicates that the Gd spin structure is collinear which is indeed to be expected in the absence of sizeable random local anisotropy. Now μ_{Co} for other alloys could be calculated based on the reasonable assumption that μ_{Gd} is independent of x. Fig. 1 shows that at 4.2 K, μ_a decreases with Gd and the compensation of the moments occurs for about x = 10.3. The Co moment is found to decrease from a value of 1.25 for x=0 to $0.9\mu_B$ for x=13.5. The variation of the Co moment with the gadolinium concentration is shown in Fig.2. This decrease in μ_{Co} is attributed on the one hand to the increased filling up of 3d bands of Co by the sp electrons from B [5] since now the relative concentration of B with respect to Co increases, and on the other hand, to hybridization of the 5d and 3d orbitals. The cobalt moment, is found to have a power-law dependence on the Gd concentration:

$$\mu_{Co} = 1.72 - 1.89\ [x/(80-x)]^{3/2} - 1.98\ [20/(80-x)] \qquad (2)$$

When x=0, then this equation describes very well the Co moment dependence in $Co_{1-x}B_x$ amorphous alloys as a function of boron concentration and is in agreement with the experimental results by Tange et al [6].

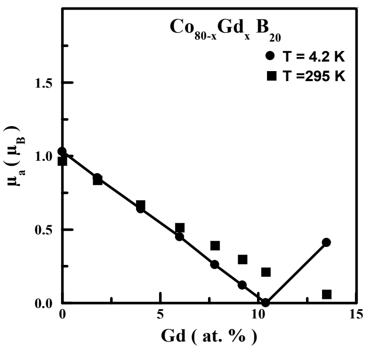

FIG. 1 : Concentration dependence of μ_a at 4.2 and 295K.

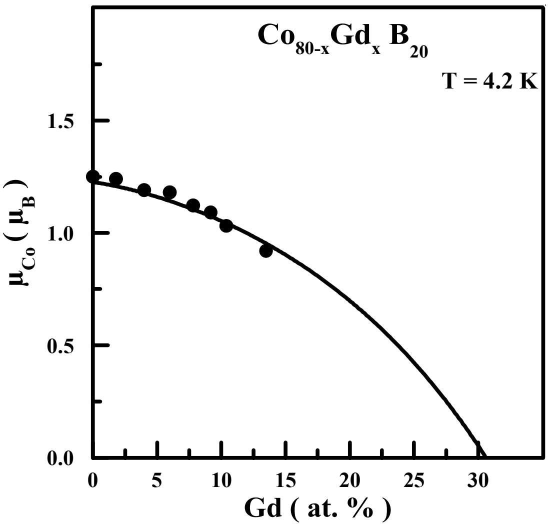

FIG. 2 : The Co moment as a function of Gd content at 4.2 K.

The temperature dependence of the magnetization of the samples was studied and some typical results are shown in Fig. 3. For the samples with x < 10.3, it is seen that with increasing Gd content, as the temperature is lowered, the magnetization first shows a broad peak and then starts decreasing. This decreasing in the magnetization is due to an increase in the magnetization of the sublattice of Gd. The magnetization compensation is seen clearly for x>10.3%. The compensation temperature is found to increase with increasing Gd concentration as to be expected.

Mean-field theory is widely used to describe the temperature dependence of magnetization and to separate the sublattice magnetizations in ferrimagnetic alloys [7, 8]. Eq. (1) can be rewritten as

$$\mu_a(T) = |M_{Co}(T) - M_{Gd}(T)| \quad (3)$$

where

$$M_{Co}(T) = (80\text{-}x)\,\mu_{Co}(T) / 100 = (80\text{-}x) g_{Co} S_{Co}(T)\,\mu_B / 100 \quad (4)$$

$$M_{Gd}(T) = x\,\mu_{Gd}(T) /100 = x\,g_{Gd} S_{Gd}(T)\,\mu_B / 100 \quad (5)$$

The sublattice magnetizations μ_{Co} and μ_{Gd} are assumed to follow the Brillouin functions;

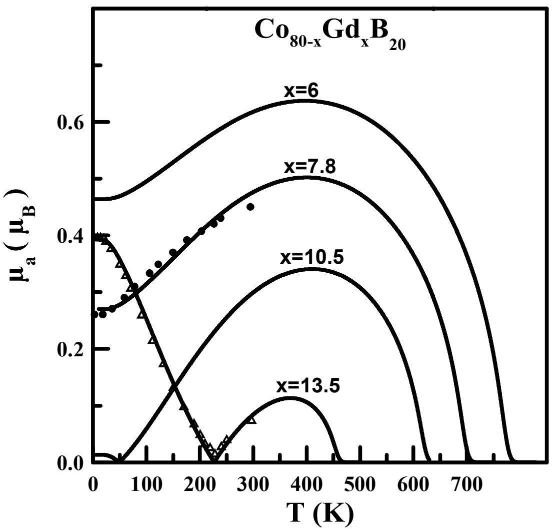

FIG. 3 The temperature dependence of the magnetization for alloys with different Gd concentrations.

$$\mu_{Co}(T) = \mu_{Co}(0K) B_{S(Co)}(\mu_{Co}(0K)\, H_{Co} / k_B T) \quad (6)$$

$$\mu_{Gd}(T) = \mu_{Gd}(0K) B_{S(Gd)}(\mu_{Gd}(0K)\, H_{Gd} / k_B T) \quad (7)$$

k_B is the Boltzmann constant. The molecular fields H_{Co} and H_{Gd} are given by

$$H_{Co} = 2J_{CoCo}Z_{CoCo}S_{Co}(T)/g_{Co}\mu_B + 2J_{CoGd}Z_{CoGd}S_{Gd}(T)/g_{Co}\mu_B, \quad (8)$$

$$H_{Gd} = 2J_{GdCo}Z_{GdCo}S_{Co}(T)/g_{Gd}\mu_B + 2J_{GdGd}Z_{GdGd}S_{Gd}(T)/g_{Gd}\mu_B, \quad (9)$$

where S_{Co} and S_{Gd} are the Co spin momentum and Gd spin momentum, respectively. Here, J_{CoCo}, J_{CoGd} and J_{GdGd} are the exchange integrals for the CoCo, CoGd and GdGd interactions, respectively, and g_i is the spectroscopic splitting factor (we take g_{Co} = 2.2 and g_{Gd} = 2). Z_{ij} (i, j = Co, Gd) is the number of nearest neighbors of the atom j for the atom i taken to be

$$Z_{CoCo} = Z_{GdCo} = 12\ (1\text{-}x/80), \quad (10)$$

$$Z_{CoGd} = Z_{GdGd} = 12\ (x/80). \quad (11)$$

Using the spin values given in table 1 and adjusting the exchange interactions J_{CoCo} and J_{CoGd}, the sublattice magnetizations M_{Co}, M_{Gd} and the alloy moment $\mu_a = |M_{Co}-M_{Gd}|$ can be calculated. From these fits the exchange interactions were extracted as function of the Gd content. The exchange interactions J_{CoGd} and J_{CoCo} extracted from the fits of the μ_a data for $6 \leq x \leq 14$ range between 16.5 10^{-16} erg and 19 10^{-16} erg and 170 10^{-16} erg and 167.10^{-16} erg, respectively. It is seen that J_{CoGd} increases when the Gd concentration increases (table 1). A similar increase in J_{RT} has been reported in intermetallic compounds and amorphous alloys also [9-11]. The 3d-4f interactions depend critically on 3d-5d hybridization according to brooks et al. [12]. Therefore the increase in J_{CoGd} would indicate an increase in 3d-5d hybridization when the Co concentration relative to Gd is decreased. The temperature dependence of μ_a is shown in Fig. 3 for different samples. It is seen that the experimental points align well with the calculated curve.

x%	S_{Co} (4.2 K)	$T_C^{(exp)}$ (K)	J_{CoCo} (10^{-16}erg)	J_{CoGd} (10^{-16}erg)	J_{GdGd} (10^{-16}erg)	$T_C^{(cal)}$ (K)
0	0.568	820	198	---	---	837
6	0.54	790	169.6	16.5	3	786
7.8	0.51	718	168	17	2	715
10.5	0.472	620	168.5	18	1	630
13.5	0.41	469	167	19	1	467

Table 1: Some magnetic parameters of $Co_{80-x}Gd_xB_{20}$ alloys .

The Curie temperatures T_C can be expressed as [13, 14]

$$3k_BT_C = a_{CoCo}+a_{GdGd}+|(a_{CoCo}+a_{GdGd})^2 - 4[a_{GdGd}a_{CoCo}-(a_{CoGd}\ a_{GdCo})]|^{1/2}, \quad (12)$$

with

$$a_{CoCo} = z_{CoCo}J_{CoCo}S_{Co}(S_{Co}+1) \quad (13)$$

$$a_{GdGd} = z_{GdGd}J_{GdGd}S_{Gd}\ (S_{Gd}+1)(g_{Gd}-1)^2 \quad (14)$$

$$a_{CoGd}\ a_{GdCo} = z_{CoGd}z_{GdCo}J_{CoGd}^2S_{Co}(S_{Co}+1)(g_{Gd}-1)^2S_{Gd}(S_{Gd}+1), \quad (15)$$

Thus knowing all the parameters, T_C could be calculated. It is seen that T_C is decreased by the addition of Gd and arises mainly from the weakening of Co-Co interaction.

IV. CONCLUSION

We have prepared amorphous $Co_{80-x}Gd_xB_{20}$ alloys by melt spinning technique and carried out magnetization study. The Co moment decreases with increasing Gd content. The various exchange integrals have been calculated using the mean field theory.

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