Magnetic properties in amorphous $Co_{95-x}Dy_xZr_5$ thin films

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Amorphous $Co_{95-x}Dy_xZr_5$ thin films were prepared by RF sputtering and their magnetic properties were studied as a function of temperature and for the composition range 0<x<30. The mean field theory has been used to explain the temperature dependence of the magnetization. The exchange interactions between Co-Co and Dy-Co atom pairs have been evaluated. The magnetic phase diagrams are presented.

Keywords: Amorphous $Co_{95-x}Dy_xZr_5$ thin films; Mean field theory; Exchange interactions

1. Introduction

Amorphous ferromagnetically soft thin films containing rare earth metals are of interest due to their industrial application. The films are also interesting from a scientific point of view as they offer the possibility to study various aspects of 3d and 4f magnetism. Contrary to crystalline materials these aspects can be investigated in a continuous concentration 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 spin-orbit interaction are known to give rise to large random anisotropy in amorphous films [1-3].

Magnetic properties of amorphous alloys are strongly affected by the lack of structural order, which causes bond and chemical disorder, resulting in magnetic moment amplitudes and exchange interaction fluctuations. In this work we describe the results of our magnetic studies of amorphous $Co_{95-x}Dy_xZr_5$ films as a function of temperature in the range 4.2-300K.

II. Experimental

The amorphous films were deposited by the RF diode sputtering techniques using Argon as a sputtering gas. We used the same deposition parameters, i.e. a pressure of the sputter gas of P_{Ar} = 2 mTorr and RF input power of 300W. During the deposition a DC field of 700 Oe was applied parallel to the film plane giving rise to an in plane uniaxial anisotropy. The amorphous structure was confirmed by X-ray diffraction using CuKα radiation. The exact composition was determined by electron probe microanalysis. The magnetization was measured by a vibrating sample magnetometer; from 4.2 to 300 K in magnetic fields up to 1.7 T.

III. Results and discussion

All films exhibit in plane hysteresis loops which are characteristic of high-quality amorphous soft ferromagnetic thin films. Along the easy axis a rectangular hysteresis loop is detected. Along the hard axis a loop with a shape characteristic of a thin film exhibiting a very well-defined in-plane uniaxial anisotropy is detected.

The experimental temperature dependence of the magnetization M of amorphous $Co_{95-x}Dy_xZr_5$ films at 1.7 T is shown in Fig. 1. The magnetization decreases with increasing Dy content. The above results are characteristic of the antiferromagnetic interaction between Dy and Co atoms which is well known. M can be written as

$$M(T) = |\,(95-x)\,\mu_{Co}(T) - x\,\mu_{Dy}(T)\,| / 100, \tag{1}$$

where μ_{Co} and μ_{Dy} are the moments for Co and Dy, respectively. For small concentrations (x<7) of Dy, the moment of Co at 4.2 K is not perturbed. So taking the value of μ_{Co} = 1.55 μ_B obtained from the alloy with x = 0 and substituting it in Eq. (1); it is possible to determine μ_{Dy}. The calculated moment is found to be 8 μ_B, which is smaller than the theoretical value of 10μ_B; this reduction could be attributed to the non-collinear and conical spin structure of Dy. This phenomenon is the resultant of the strong random anisotropy of Dy and the antiferromagnetic J_{DyCo} interactions which normally lead to a "sperimagnetic" structure [4].

Now μ_{Co} for the other alloys can be calculated based on the reasonable assumption that μ

$_{Dy}$ is independent of x. The Co moment is found to decrease from a value of 1.55 μ_B for
x = 0 to 1.15 μ_B for x = 26. The variation of the Co moment with the Dy concentration is shown in Table I. The decrease of μ_{Co} with increasing Dy concentration can be understood as due to an increasing filling of the 3d spin-up band of the Co atom by the $6s^2/5d$ conduction electrons of the Dy atom.

The temperature dependence of the magnetization can analyzed in terms of the mean-field theory [5]. Using μ_{Co} given in table I and adjusting the exchange interactions J_{DyCo} and J_{CoCo} the sublattice magnetization M_{Co} and M_{Dy} and the magnetization $M = |M_{Co}-M_{Dy}|$ can be calculated. The solid lines in Fig. 1 represent the calculated results for $Co_{95-x}Dy_xZr_5$ alloys. The exchange fluctuations caused by the structural disorder affect the shape of the M curves. This influence has been omitted because at least one additional parameter would have to be adjusted. The calculated dependencies demonstrate that a good fit to the experimental data was achieved for $Co_{95-x}Dy_xZr_5$ alloys. From these fits the exchange interactions were extracted as a function of the Dy content. The results are shown in Table I.

Table I: Some magnetic parameters of amorphous $Co_{95-x}Dy_xZr_5$ thin films.

x	$\mu_{Co}(\mu_B)$ at 4.2 K	J_{CoCo} (10^{-21} J)	J_{DyCo} (10^{-22}J)
9	1.52	1.33	1.5
12.5	1.48	1.3	1.51
17.5	1.38	1.31	1.5
19.5	1.34	1.2	1.48
22	1.27	1.2	1.1
26	1.15	1.1	0.95

The molecular field coefficient n_{DyCo} has been derived from J_{DyCo} by means of the expression [6]

$$n_{DyCo} = 2\, Z_{DyCo}\, J_{DyCo}\, (g_{Dy} - 1)\, (g_{co} - 1)] \,/\, N_{Co}\, g_{Co}\, g_{Dy}\, \mu_B^2, \quad (2)$$

where Z_{DyCo} denotes the number of nearest Co neighbours of Dy atoms, $g_{Co(Dy)}$ the spectroscopic splitting factor of Co(Dy) and N_{Co} is the number of Co atoms by unit of mass. We have assumed Z_{DyCo} = 15, corrected to the Co concentration.

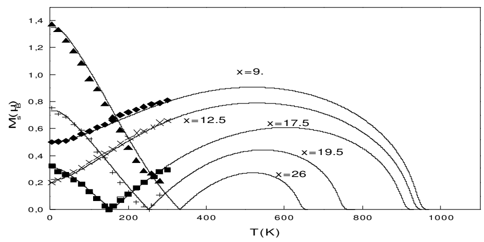

Fig. 1. The temperature dependence of the magnetization for the amorphous $Co_{95-x}Dy_xZr_5$ films. The solid lines were calculated from the mean-field theory

Taking the value of n_{DyCo} derived as above and knowing the value of $|M_{Co}-M_{Dy}|$ we can calculate the critical field $H_{crit.1}$, at which the antiferromagnetic coupling starts breaking down, using the equation [7]

$$H_{crit1} = n_{DyCo}\, |M_{Co}-M_{Dy}|. \quad (3)$$

As the applied field H is further increased, there is a second critical field $H_{crit.2}$ above which the Dy and Co moments are aligned parallel to each other and one has forced ferromagnetic ordering. This critical field is given by the relation [7]

$$H_{crit.2} = n_{DyCo}\, (M_{Co} + M_{Dy}). \quad (4)$$

The magnetic phase diagram presented in Fig. 2 shows the dependence of the magnetic structure of these ferrimagnetic films on external fields.

The critical field strengths of Eqs. (3) and (4), between which there are canted configurations, and, for fixed field strength, the critical temperatures T_l and T_u which bound the non-collinear phase ($H_{crit.1}<H<H_{crit.2}$), can be given by [8]

$$K_B T_l = \mu_{Dy}\, (n_{DyCo}\, M_{Co}(T) + H) \,/\, B_{S(Dy)}^{-1} [(n_{DyCo}\, M_{Co}(T) + H) \,/\, n_{DyCo}\, M_{Dy}(0)] \quad (5)$$

$$K_B T_u = \mu_{Dy}\, |\, n_{DyCo}\, M_{Co}(T) - H \,| \,/\, B_{S(Dy)}^{-1} [\, |\, n_{DyCo}\, M_{Co}(T) - H \,| \,/\, n_{DyCo}\, M_{Dy}(0)]. \quad (6)$$

Fig. 3 shows the phase diagrams in the H-T plane for amorphous $Co_{77.5}Dy_{17.5}Zr_5$ thin films. At all phase boundaries the transitions are second order.

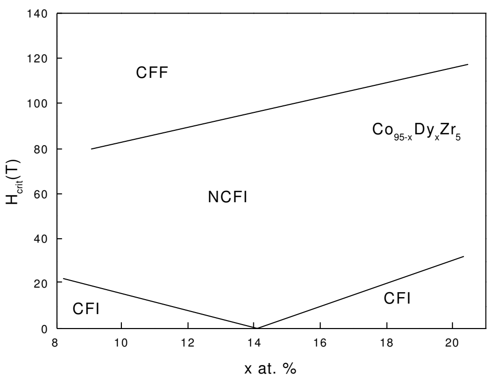

Fig. 2. Magnetic phase diagram for amorphous $Co_{95-x}Dy_xZr_5$ films alloys at 4.2 K. The full lines show the lower H_{crit1} and upper H_{crit2} critical fields calculated within the two-sublattice model. CFI - collinear ferrimagnet, NCFI - non-collinear ferrimagnet, CFF - collinear field-forced ferromagnet.

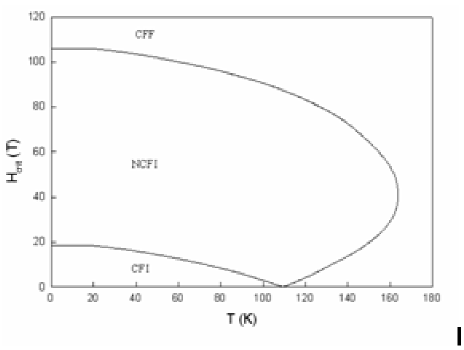

Fig. 3. Magnetic phase diagram for the amorphous $Co_{77.5}Dy_{17.5}Zr_5$ films in H-T plan.

IV. Conclusion

The magnetic properties of amorphous $Co_{95-x}Dy_xZr_5$ films were investigated with respect to their compositional and temperature dependence. The magnetization was analysed in terms of the mean-field theory. The Co moment and the exchange interactions J_{CoCo} and J_{DyCo} were evaluated. The angled region can be described by a magnetic phase diagrams in H-x and H-T planes.

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