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SPIN WAVE SPECTRA IN AMORPHOUS $Co_{1-x}Zr_x$ THIN FILMS HAVING EXCEPTIONALLY UNIFORM MAGNETIC PROPERTIES

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Abstract. – Amorphous $Co_{1-x}Zr_x$ thin films present exceptionally uniform magnetic properties when the sputtering parameters are carefully optimized as revealed a study by F.M.R. In the standing spin wave spectra all modes follow a quadratic dispersion law with an excellent precision. The value and variations of the spin wave amplitude confirm that the only existing magnetic inhomogeneity is a fairly small structure related random anisotropy which decreases with increasing Zr content.

The characteristics of the standing spin wave (S.S.W.) spectra detected by ferromagnetic resonance (F.M.R.) are extremely sensitive to the magnetic inhomogeneities which exist in a ferromagnetic film. Only in thin films which exhibited small inhomogeneities well defined S.W. spectra was obtained which could be interpreted by simple models [1]. The inhomogeneities were attributed to a departure from a "perfect material" because of the formation of some chemical or structural defects which developped during the preparation process.

Here we report a study performed on amorphous $Co_{1-x}Zr_x$ thin films. It will be shown that the characteristics of the S.W. spectra are determined by the amorphous peculiar local structure, but the preparation related defects appear to be negligibles.

The investigations were performed for the concentration range $0.055 \leq x \leq 0.15$ on films of thickness $(0.195 \pm 0.005\mu m)$. The films were deposited by r.f. sputtering and the sputtering parameters were carefully optimized. During the deposition a magnetic field of 700 Oe was applied parallel to the film plane. The presence of this field favorize the formation of an extremely well defined amorphous state and the elimination of microcrystals [2, 3]. The base pressure was 2×10^{-7} Torr and that of the argon sputter gas P_{AR} 2 mTorr. We used such a low P_{AR} in order to avoid the formation of high anisotropy trigonal clusters [2, 3] and minimize the value of the induced uniaxial anisotropy H_k. The r.f. input power was 300 W and the deposition rate 130 Å/min.

The F.M.R. measurements were carried out at $f = 9,8$ GHz by a standard spectrometer. $4\pi M_s$, g and H_k were computed from the three resonance fields corresponding to the uniform mode in perpendicular ($H_\perp$) and in parallel orientation with the applied field perpendicular and parallel to H_k.$4\pi M_s$ *versus* concentration follows nicely a linear law as a function of x in accordance with the Friedel's rule (Fig. 1). $g = 2.18 \pm 0.02$ and concentration independent. H_k decreased smoothly from 40 to 25 Oe with increasing Zr content.

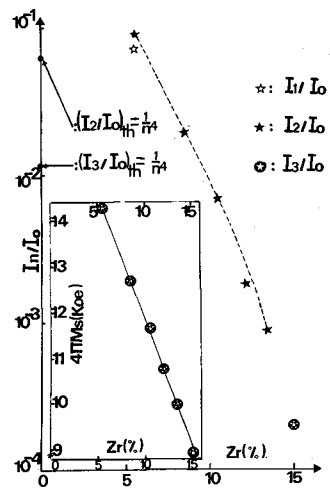

Fig. 1. – Variation of the intensity of the first detected S.W. mode in films having various Zr concentration computed from V.I. model. In the inset $4\pi M_s = f(x)$.

The amorphous $Co_{1-x}Zr_x$ are soft ferromagnets with negligible magnetostriction so the Néel type surface anisotropy is negligible. In such a material the most probable origin of magnetic inhomogeneity is the volume inhomogeneity (V.I.) [1]. Let us consider the classical V.I. model developped for small defects related to the preparation process [1]. Here one assumes that the internal field fluctuates slowly around a mean value so $(H_i)_{eff} = \langle H_i \rangle + \delta H_i$ with $\delta H_i \ll \langle H_i \rangle$. It can be shown that the resonance fields corresponding to higher order modes (typically $n > 2$) follow a quadratic dispersion law $H_n = \omega / \gamma - \langle 4\pi M_s \rangle_{eff} + Dn^2\pi^2 / L^2$ (where n is an integer and L the film thickness). The low order modes deviate slightly from this law and the inhomogeneity is of the order $\delta H \approx H_0 - H_0'$. H_0 and H_0' are the resonance fields corresponding respectively to the experimental uniform mode and the extrapolaed value to $n = 0$ of the experimental dispersion law. The intensity of the higher order spin wave modes follow the law $I_n \propto 1 / n^4$ while that of the lower ones is in the range $1 / n^4 < I_n < 1 / n^2$.

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In the present case the S.S.W. spectra corresponding to the films of various concentrations exhibit the following characteristics:

I) the resonance linewidth ΔH_0 corresponding to the uniform mode increases smoothly from 45 Oe to 60 Oe with increasing Zr content. The value of ΔH_0 is the same for $H_\perp$ and $H_\parallel$;

II) the S.S.W. spectra could be detected only for $H_\perp$. Following the concentration 5 to 7 modes were detected;

III) excepted the sample with $x = 0.055$ (called hereafter sample A) on all the other films the field for resonance corresponding to all modes including the uniform resonance follows a quadratic dispersion law with an extremely high precision. A less square computation including all mode gave a correlation coefficient of 0.9999. From our knowledge it is the first time that the experimental resonance fields corresponding to the varius modes *and including in particularly the uniform resonance* follow a quadratic variation of n with such a high precision in a metallic film. This result show that $\delta H = 0$, so in accordance with the V.I. model the volume inhomogeneities should be negligibles. On sample A the two lowest order modes deviate from the quadratic law and $\delta H \approx 100$ Oe;

IV) the intensities of the various S.W. modes are fairly weak, result which confirm also that the inhomogeneities are extremely small. A consequence of the high homogeneity is that – excepted on sample A – the S.W. mode $n = 1$ could not be detected because the proximity of the uniform resonance. As a result the lowest order as resolved S.W. mode was $n = 2$ and on film with the highest Zr concentration $n = 3$. On a given sample I_n / I_0 decreases with increasing mode number but much faster than $1 / n^4$ i.e. the law predicted by the V.I. model;

V) a very important result is the variation I_2 / I_0 for films of various composition. As shown in figure 1. I_2 / I_0 decreases extremely rapidly when the concentration of Zr in the film increases. On all samples – excepted sample A – the value of I_2 / I_0 is at least an order of magnitude smaller than $1 / n^4 = 1/16$ i.e. the value predicted by the V.I. model.

The characteristic reported in III-V show the high magnetic uniformity of the samples, but the overall results can not be explained by the V.I. model. However in ordre that the S.W. modes should be excited the films must exhibit some magnetic inhomogeneities. It is believed that in the present case it is intrinsic and related to the peculiar amorphous structure. A structural study revealed that when these $Co_{1-x}Zr_x$ films are deposited at low P_{AR} the structure is formed of a random continuous matrix of clusters with icosahedral and low anisotropy (f.c.c. like) octahedral clusters. When the Zr content in the films increases the local structure becomes more disordered, the octahedral clusters being progressively deformed and take an icosahedral configuration. The magnetic inhomogeneity is the local anisotropy K_1, related to octahedral clusters,K_1 decreases with increasing Zr content result which explain the as-observed variaion of I_2 / I_0. Actually a new model is developped which takes into account the short range variation of K_1 with respect of the thickness of the film as determined by the diameter of the clusters (typically 20 to 30 Å). The relatively large inhomogeneity observed in sample A is related to its Zr content which is closed to the minimum necessary for the obtention of an amorphous state.

The values of exchange stiffness D and exchange constant A corresponding to films of various composition, are reported in figure 2 *versus* magnetization. These results appear to be fairly consistent if one compare them with those obtained on similar compounds. In crystallin fcc Co $A = 2,5 \times 10^{-6}$ erg/cm as determined by neutron diffraction [4] while we find for $Co_{94.5}Zr_{5.5}$ $A = 2.15 \times 10^{-6}$ erg/cm (Fig. 2). For $x = 0.15$ D differs by less than 15 % in $Co_{85}Ti_{15}$ [5] and $Co_{85}Zr_{15}$.

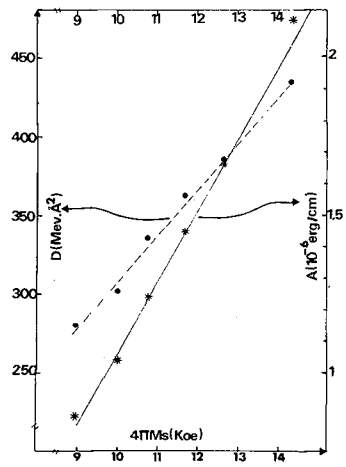

Fig. 2. – Variation of D and A *versus* the magnetization of the layers.

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