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# DEPENDENCE OF THE SWR LINEWIDTH ON THE WAVEVECTOR IN AMORPHOUS THIN FILMS*

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ABSTRACT. The linewidth of volume Spin Wave Resonance (SWR) modes in FeB metallic glasses have been studied at X-band frequencies for temperatures ranging from 4 K to 295 K in perpendicular configuration. It was found that fluctuations in the exchange interaction parameter of the spin system in amorphous state affects the linewidth $\Delta H_n$ of the $n$-th mode. For wavevectors $k_n$ above a critical value, the linewidth $\Delta H_n \sim k_n^{0.7\pm0.1}$ and does not depend on the temperature.

## 1. INTRODUCTION

There are several models of amorphous structures that can be applied for metallic glasses. The hard spheres model [1] assumes that some empty space exists, a so called free volume, acting as vacancy-like defects and enabling reorientation of atom pairs. In the simple chemical twinning model [2] frustration and concentration fluctuations are considered as the source of disorder. The microcrystallite model [3] considers ordering of crystallite-like clusters.

Topological disorder in amorphous substances must lead to some spatial fluctuations of local structural and magnetic parameters [4]. In a phenomenological approach, the fluctuations of a parameter are described by static moments of stochastic functions: the mean value of the parameter, the amplitude of the fluctuations $\sigma$ and the correlation length $\xi$. We expect the correlation length perhaps of several interatomic distance in amorphous materials and so suitable experimental techniques must be applied to sense the effects on this micro scale.

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Therefore, it is rather in a limit of greater $k_n$ vectors that we may observe the fluctuations. Ignatchenko et al. [5, 6] suggested an SWR experiment. Their phenomenological model assumes long range fluctuations of the saturation $M$, exchange constant and anisotropy field. Each of the fluctuations alters the quadratic dispersion relation for crystalline phases in a characteristic way. Therefore, we may extract information from experiment on the fluctuation parameters such as $\sigma$ and $\xi$ and also may indicate which mechanism is predominated. Such an experiment on FeB amorphous thin films was presented in our earlier paper [7].

## 2. MODEL

We assume that the spin system in ferromagnetic materials can be described by the Hamiltonian

$$\varkappa=\tfrac{1}{2}\alpha(\nabla \boldsymbol{M})^2-\tfrac{1}{2}\beta(\boldsymbol{M}\cdot\boldsymbol{l})^2-\boldsymbol{H}\cdot\boldsymbol{M}+(1/8\pi)(\boldsymbol{H}_m)^2, \tag{1}$$

where $\alpha$ is the exchange integral, $\boldsymbol{M}$ the magnetization, $\beta$ the uniaxial anisotropy constant with easy axis in the $\boldsymbol{l}$-direction, $\boldsymbol{H}$ the external magnetic field and $\boldsymbol{H}_m$ is the demagnetization field.

If, for example, the exchange integral $\alpha(\boldsymbol{r})$ is a stochastic function of the space coordinates $\boldsymbol{r}$ with mean value $\alpha$ and standard deviation from the average $\sigma$, then the dispersion relation $\omega(k)$ is given by [6]

$$L(\boldsymbol{k})=\sigma^2\int\frac{(\boldsymbol{k}\cdot\boldsymbol{k}')^2S(\boldsymbol{k}-\boldsymbol{k}')}{L(\boldsymbol{k}')}\,d^3\boldsymbol{k}', \tag{2}$$

where

$$L(\boldsymbol{k})=(\omega-\omega_0)/\gamma\alpha M-\boldsymbol{k}^2. \tag{3}$$

For crystalline ferromagnet, when $\sigma=0$, one gets $L(\boldsymbol{k})=0$ from eq. (2) and then we recover from eq. (3) the standard quadratic dispersion relation $\omega=\omega_0+\gamma\alpha M\boldsymbol{k}^2$, where $\omega_0$ is the spin wave frequency for the uniform mode $\boldsymbol{k}=0$. For systems where $\sigma\neq 0$, such as in amorphous state, we must perform integration in eq. (2) for an assumed form of the Fourier transform $S(\boldsymbol{k}-\boldsymbol{k}')$ of the normalized correlation function $K(\boldsymbol{r}-\boldsymbol{r}')$. The model correlation function was chosen [6] in the form of the Karman function

$$K(\boldsymbol{r})=(1+r/\xi)\,e^{-r/\xi}, \tag{4}$$

where $\xi$ is the correlation length associated with the correlation wave vector $k_\alpha$ (of quantity $\alpha$, here the exchange integral),

$$k_\alpha=1/\xi. \tag{5}$$

Carrying out the integration in eq. (2) we get the dispersion relation in the limiting cases of small and large wavevectors:

$$\omega = \omega_0 + \gamma\alpha M(1 - \tfrac{1}{3}\sigma^2)k^2, \text{ for } k \ll k_\alpha, \quad (6)$$

$$\omega = \omega_0 + \gamma\alpha M(1 - \tfrac{5}{4}\sigma^2)k^2 + \tfrac{33}{16}\sigma^2 k_\alpha^2, \text{ for } k \gg k_\alpha. \quad (7)$$

It is seen that $\omega \sim k^2$ as in the crystalline state $\sigma = 0$ but the slope of the predicted straight line on the plot of $\omega$ vs $k^2$ is smaller. Moreover, the slope is different for small and large $k$ and we also expect a kink or a deflection at $k \cong k_\alpha$.

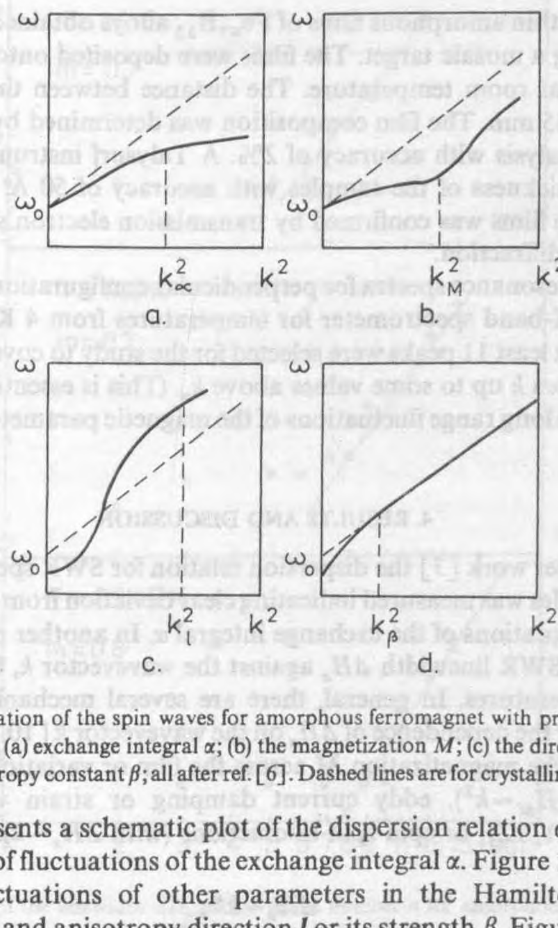


Fig. 1. Dispersion relation of the spin waves for amorphous ferromagnet with predominant spatial fluctuations, $\sigma \neq 0$, of: (a) exchange integral $\alpha$; (b) the magnetization $M$; (c) the direction $l$ of the easy axis, and (d) the anisotropy constant $\beta$; all after ref. [6]. Dashed lines are for crystalline state when $\sigma = 0$.

Figure 1a presents a schematic plot of the dispersion relation $\omega$ as a function of $k^2$ for the case of fluctuations of the exchange integral $\alpha$. Figure 1b-d illustrates the effect of fluctuations of other parameters in the Hamiltonian (1): the magnetization $M$ and anisotropy direction $l$ or its strength $\beta$. Figure 1 was taken after ref. [6].

We often think of the dispersion relation as a function $\omega(k)$ with no imaginary part. This is so for systems with perfect translational symmetry as in the crystalline state where there is no spin wave energy dissipation due to the scatterings on inhomogeneities of the fluctuating magnetic parameter. If, however, $\sigma \neq 0$ then some energy losses take place which manifest themselves by the fact that $\mathrm{Im}(k) \neq 0$ leading to a finite spin wave mode linewidth given by [8]

$$\Delta H_f = \frac{D}{g\mu_B} \sigma^2 f(k_\alpha, k), \tag{8}$$

where $D$ is the spin wave stiffness constant, $g$ the Lande factor and $f(k_\alpha, k)$ a function of spin wavevector $k$.

## 3. EXPERIMENT

We studied thin amorphous films of $Fe_{47}B_{53}$ alloys obtained by rf sputtering technique using a mosaic target. The films were deposited onto glass substrates Corning 7059 at room temperature. The distance between the target and the substrate was 45 mm. The film composition was determined by means of X-ray microprobe analysis with accuracy of 2%. A Talysurf instrument was used to measure the thickness of the samples with accuracy of 50 Å. The amorphous structure of the films was confirmed by transmission electron spectroscopy and also by X-ray diffraction.

Spin wave resonance spectra for perpendicular configuration were taken with a microwave X-band spectrometer for temperatures from 4 K to 295 K. Only samples with at least 11 peaks were selected for the study to cover a wide range of spin wavevectors $k$ up to some values above $k_\alpha$. (This is essential to observe the influence of the long range fluctuations of the magnetic parameters in amorphous films.)

## 4. RESULTS AND DISCUSSION

In our earlier work [7] the dispersion relation for SWR spectra consisting of 14 volume modes was measured indicating clear deviation from the quadratic law due to the fluctuations of the exchange integral $\alpha$. In another paper [9] we also measured the SWR linewidth $\Delta H_n$ against the wavevector $k$, for $k > k_\alpha$, and for different temperatures. In general, there are several mechanisms found to be responsible for the dependence of $\Delta H_n$ on the wavevector $k$ [10, 11]: variations in magnitude of the magnetization $M$ across the film or variation of the thickness $L$ (yielding $\Delta H_M \sim k^2$), eddy current damping or strain variations (giving $\Delta H_E \sim k^{-2}$) [11, 12], or spin-spin interactions (with $\Delta H_s \sim k$). Here we assume a power law

$$\Delta H_n \sim k^m, \tag{9}$$

where $n$ is the mode number and we assume a simplified relation between $k$ and $n$ for a film of thickness $L$,

$$k = n\frac{\pi}{L}. \tag{10}$$

Figure 2a-c shows the $n$ dependence of $\Delta H_n$ in a logarithmic scale for $Fe_{47}B_{53}$ thin films for three temperatures [13]. It is seen that there is no significant

$n$ dependence of the linewidth up to some particular value of $n$. For $k > k_\alpha = n\pi/L$ we have $\Delta H_n \sim n^m$ where $m$ is about 0.8. The inflection of the curve takes place at the same value $k_\alpha$ as that obtained in paper [7] for the inflection of the dispersion relation caused by exchange integral fluctuations. We also observed that neither $m$ nor $k_\alpha$ depends on the temperature $T$.

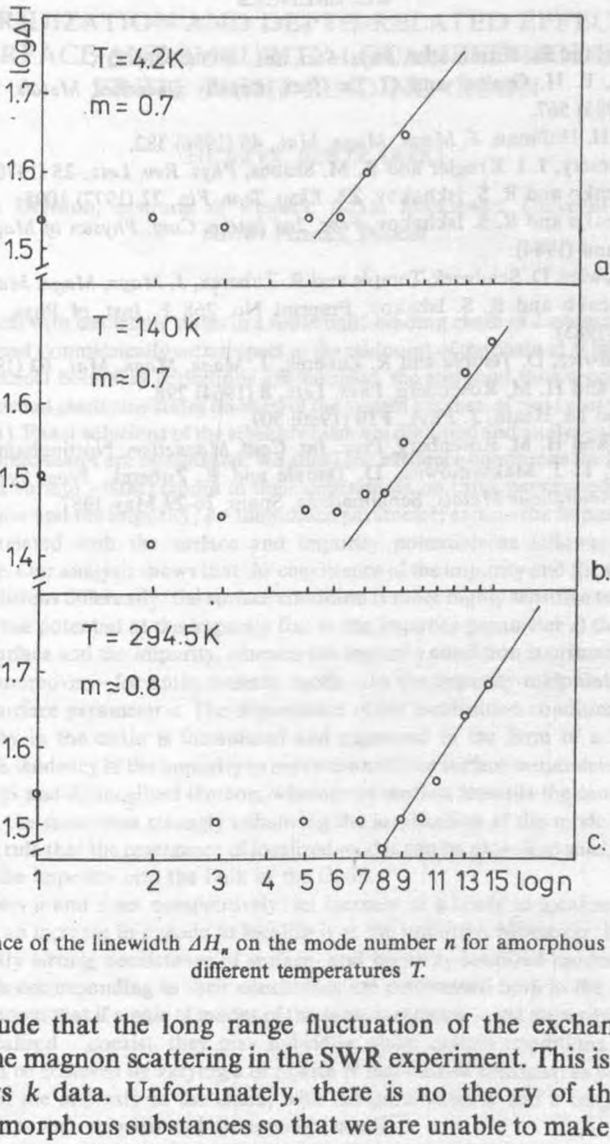


Fig. 2. Dependence of the linewidth $\Delta H_n$ on the mode number $n$ for amorphous $Fe_{47}B_{53}$ films for different temperatures $T$.

We conclude that the long range fluctuation of the exchange parameter $\alpha$ influences the magnon scattering in the SWR experiment. This is well apparent in the $\Delta H_n$ vs $k$ data. Unfortunately, there is no theory of these scattering processes in amorphous substances so that we are unable to make a comparison with a theoretical model. We hope to produce some calculations in that direction later on.

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