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SPIN-WAVE RESONANCE IN THE $FeBr_2$ METAMAGNETIC THIN FILM*

W. RUDZIŃSKI

Faculty of Physics, Adam Mickiewicz University
Umultowska 85, 61-614 Poznań, Poland

The spin-wave resonance in the thin $FeBr_2$ field-induced metamagnet in the paramagnetic phase with the (001) surfaces and at low temperatures is examined theoretically. It is found that the absorption spectrum is strongly affected by modifications of the surface exchange parameters. Also, the conditions for the appearance of various surface and bulk spin-wave features are discussed.

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1. Introduction

Recently, the semi-infinite as well as thin-layered structures of field-induced metamagnets (FIM) have been the subject of theoretical studies of their surface properties, and it has been shown that in addition to the bulk spin-wave excitations at low temperatures also surface-spin waves (SSW) localized near the surfaces may occur in both antiferromagnetic (A) and paramagnetic (P) phases. The numerical results obtained in Refs. [1, 2] for the (001) surface of the semi-infinite $FeBr_2$ and $FeCl_2$ samples have revealed a strong dependence of SSW properties on the crystal structure of these materials. Moreover, it has been found that a modification of the frequency separation between the surface and bulk dispersion curves, the shape of dispersion curves as well as the appearance of some new qualitative features of magnons propagating in the direction parallel to the surface layer evidently depend on the surface-induced modifications of the magnetic interactions. In Ref. [3] a theoretical approach of calculating the spin-wave energies for surface and bulk standing spin waves has been proposed for a thin film of FIM with disturbed surface exchange parameters. Thus, different spin-wave behaviour corresponding to different values of the exchange parameters and to different film thicknesses has been observed.

In this paper we investigate the effect of modifications of exchange interactions on the spectral intensities of the spin-wave resonance (SWR) occurring in

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the $FeBr_2$ thin film in the P phase and at low temperatures. It will be shown that, when the competing surface intralayer and interlayer exchange parameters are allowed to differ from their bulk values, a full range of SWR qualitative features is evaluated.

2. Model and method

The system under study is a thin film of FIM consisting of N monoatomic layers parallel to the (001) plane. In A phase each layer is oriented in a direction opposite to that of the neighbouring layers. If the magnetic field H is applied perpendicularly to the surfaces then, at a threshold field H_{AP}, a transition occurs to P phase of high magnetic moment. The system will be represented by the following Hamiltonian, known from Ref. [4], as the three-ion model of FIM:

$$\begin{aligned}\mathcal{H} = &-\frac{1}{2}\sum_{rr'n} I_{rr'n}(\boldsymbol{S}_{rn}\boldsymbol{S}_{r'n} + \sigma' S^z_{rn}S^z_{r'n}) \\ &+\frac{1}{2}\sum_{rn,n-1} J_{rn,n-1}(\boldsymbol{S}_{rn}\boldsymbol{S}_{rn-1} + \sigma S^z_{rn}S^z_{rn-1}) \\ &+\frac{1}{2}\sum_{rn,n+1} J_{rn,n+1}(\boldsymbol{S}_{rn}\boldsymbol{S}_{rn+1} + \sigma S^z_{rn}S^z_{rn+1}) - g\mu_{\mathrm{B}}H\sum_{rn} S^z_{rn} \\ &+\frac{1}{2}\sum_{rr'n,n-1} D_{rr'n,n-1}[S^z_{rn}S^z_{rn-1}(S^z_{r'n})^2 + S^z_{rn}S^z_{rn-1}(S^z_{r'n-1})^2] \\ &+\frac{1}{2}\sum_{rr'n,n+1} D_{rr'n,n+1}[S^z_{rn}S^z_{rn+1}(S^z_{r'n})^2 + S^z_{rn}S^z_{rn+1}(S^z_{r'n+1})^2]. \end{aligned} \tag{1}$$

Here $\boldsymbol{r}$ denotes the two-dimensional position vector of spins belonging to a given layer labelled by the index n, where $n = 0, 1, 2, \ldots, (N-1)$ with $n = 0$ and $n = N-1$ denoting the surface layers, where N is an even number. I stands for the ferromagnetic intralayer exchange parameter, whereas J is the antiferromagnetic interlayer one. We assume that the exchange parameters for $n = 0$ and $n = N-1$ take the values I_s and J_s which in general are different from their bulk values I_{b} and J_{b}. The coefficients σ and σ' in Eq. (1) characterize the uniaxial two-ion anisotropy terms, H is the magnetic field applied in the z-direction, whereas the parameter D represents the three-ion anisotropic interactions between adjacent layers.

In order to perform the SWR calculations, explicit analytical expressions for the dispersion relations as well as for spin-wave amplitudes are found within the procedure proposed in Ref. [3] for description of the surface properties of finite FIM crystal structures.

3. Numerical results

Figure 1 presents the stability diagram $\beta(\gamma)$, where $\beta = I_b - I_s$ and $\gamma = J_b - J_s$, plotted for the $FeBr_2$ thin film with $N = 10$ monoatomic layers. Moreover, the following values for the bulk interaction parameters were taken: $I_b = 23.22$ (1/cm), $J_b = 1.45$ (1/cm), $\sigma = \sigma' = 0.28$, and $D = 2.45$ (1/cm). The (β, γ)-plane of this diagram consists of five areas corresponding to different properties of standing spin waves: (i) below the band C for each pair (β, γ) we have: two optical modes with $N - 2$ bulk modes in the A region; one optical mode

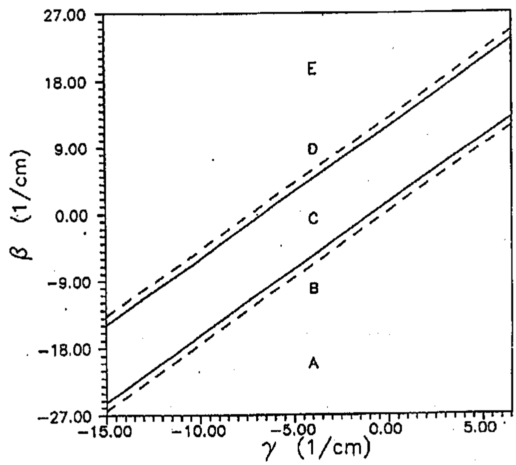

Fig. 1. Stability diagram $\beta(\gamma)$ for the $FeBr_2$ thin film in the P phase and with $N = 10$. The areas A–E correspond to different types of spin-waves: surface optical and bulk modes (A, B); bulk modes (C); surface acoustic and bulk modes (D, E).

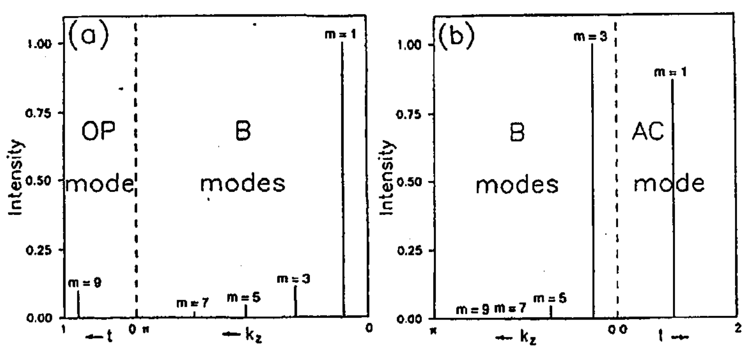

Fig. 2. SWR intensities (in arb. units) for the $FeBr_2$ thin film in the P phase and with $N = 10$ and for selected values of β ($\gamma = 0$ (1/cm)). Units on the horizontal axis are proportional to the $\boldsymbol{k}$ wave vector along the z-direction for bulk (B) peaks or to the t number for the acoustic (AC) and optical (OP) surface peaks. The β values were taken as follows: –5 (1/cm) (a), 20 (1/cm) (b).

with $N-1$ bulk modes in the B region; (ii) only bulk modes represented by the C band; (iii) above the C band for each pair (β, γ) we have: one acoustic mode with $N-1$ bulk modes in the D area; two acoustic modes with $N-2$ bulk modes in the E area.

From Fig. 2 it is evident that the localization degree of the SSW as well as changes of the positions and intensities of the SWR peaks strongly depend on the disturbances of the surface exchange parameters. Using the diagram (β, γ) plotted for a fixed N, one may observe, besides the growing bulk SWR peaks, an increase in the SSW optical or SSW acoustic spectral intensities. Thus, magnons reveal their bulk or "localized" nature due to changes of strength of pinning of the spins excited near the surface layers.

4. Final remarks

The results obtained in this paper as well as the results of earlier studies [3] provide much material for experimental verification by the SWR technique. The stability diagrams together with the absorption spectra indicate the area where one should expect surface spin stability while searching for standing spin waves lying in the bulk, surface acoustic or surface optical regime. Moreover, the derived dispersion relations and SWR characteristics allow establishing the conditions for a FIM sample to provide the spectral intensities sufficiently large for experimental detection.

On the theoretical side, such problems as incorporation of the effects of modified anisotropy constants at the surface, calculations for antisymmetric boundary conditions as well as the quantitative description of the surface reconstruction are still open to discussion.

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