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Far-infrared magneto-spectroscopy of bulk and surface magnetic excitations in FeF_2

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Abstract

We have investigated magnetic polaritons propagating in FeF_2 by high resolution far-infrared reflection and attenuated total reflection (ATR) spectroscopy. Highly non-reciprocal behaviour of the reflectivity, R, i.e. $R(+H_0) \neq R(-H_0)$ is observed in an applied magnetic field H_0. The results have been used to determine the magnetic polariton dispersion curves. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Spin waves – antiferromagnetic; Spectroscopy – far-infrared; Magneto-optics; Polariton; Surface waves

We have used far-infrared spectroscopy [1] to investigate magnetic polaritons in the bulk uniaxial antiferromagnet (AFM) FeF_2. Much theoretical work [2–4] has been directed towards understanding magnetic polaritons in AFMs but very little experimental work has been reported previously: this is the first comprehensive experimental investigation of bulk and surface magnetic polaritons and surface resonances in these materials. FeF_2 is a simple prototype 3D magnetic crystal, so it was chosen for this investigation to establish the basis for future work on thin AFM films and multilayers, which have significant potential device applications in, for example, signal processing in the THz frequency range. Measurements were made using polarised oblique incidence reflection at 45° and attenuated total reflection (ATR) using Si prisms cut for different incident angles with the sample in a vertical magnetic field, H_0, of up to 7 T in the Voigt configuration. ATR provides the wave vector enhancement required to couple to surface excitations; we have recently reported the first observation of magnetic surface polaritons in a uniaxial AFM, FeF_2 [5], using this technique.

We now report reflectivity and ATR (at 30°) measurements in the temperature range 1.6–30 K. In an applied field the doubly degenerate spin wave is Zeeman-split and two resonances are observed at $\omega_R \pm \gamma H_0$, where ω_R is the resonant frequency at zero field and γ is the gyromagnetic ratio. In Fig. 1 we show the temperature dependence of the reflectivity in s-polarisation in a weak magnetic field ($H_0 = \pm 0.3$ T) with the easy axis parallel to H_0. The observed features remain virtually unchanged

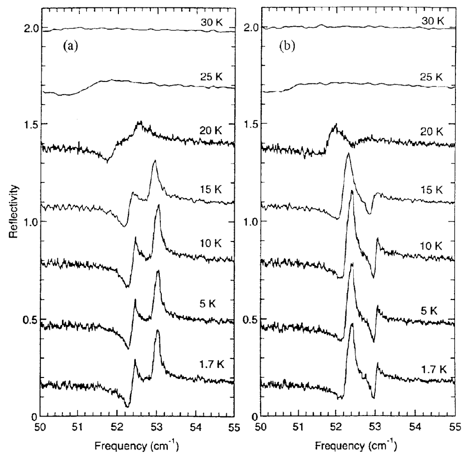

Fig. 1. Temperature dependence of the s-polarised reflection spectra of FeF_2 with applied static magnetic fields of (a) $H_0 = +0.3$ T, (b) $H_0 = -0.3$ T. Resolution: $0.02\ cm^{-1}$ up to 20 K; otherwise $0.125\ cm^{-1}$. All spectra other than those for 1.7 K have been shifted vertically for clarity.

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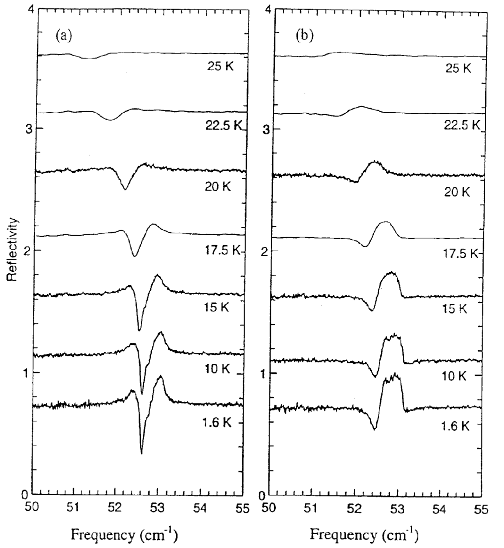

Fig. 2. Temperature dependence of the s-polarisation ATR spectra of FeF_2 with applied static magnetic fields of (a) $+0.15$ T and (b) -0.15 T. Resolution and shifts of spectra as in Fig. 1.

up to about 15 K, and at higher temperatures they shift to lower frequencies and broaden significantly. The frequency shifts are caused by the decrease in exchange and anisotropy fields with increasing temperature, and the line broadening is probably due to magnon-magnon interactions; the temperature dependence of the linewidth should provide information on these nonlinear processes. The results of ATR measurements in the same configuration with $H_0 = \pm 0.15$ T are shown in Fig. 2. At low temperatures a surface magnetic polariton, the sharp dip in Fig. 2a near 52.6 cm^{-1}, is clearly resolved. By fitting calculated curves (not shown) to the spectra for 1.6 and 1.7 K in Figs. 1 and 2 we determined the parameters required to calculate the dispersion curves shown in Fig. 3 [8], and the spectra can be understood with reference to Fig. 3. In Fig. 1 the two reststrahl regions (i.e. peaks) arise from the gaps between the bulk bands, and the sharp dips arise from the surface resonances. In Fig. 2 the flat regions below about 52 cm^{-1} and above about 53.5 cm^{-1} are due to coupling to the lower and upper bulk regions, respectively. The relatively narrow middle bulk band is seen in Fig. 2a as a slight shoulder in the spectra near 52.8 cm^{-1}, and in Fig. 3b as a weak dip between the two reststrahl regions. The results clearly demonstrate the highly non-reciprocal behaviour of the reflectivity, R, i.e. $R(H_0) \neq R(-H_0)$ [6, 7]; this has potential applications for signal processing in the far infrared since the large change in the reflectivity for $\pm H_0$ could be employed, for example, in making tunable isolators.

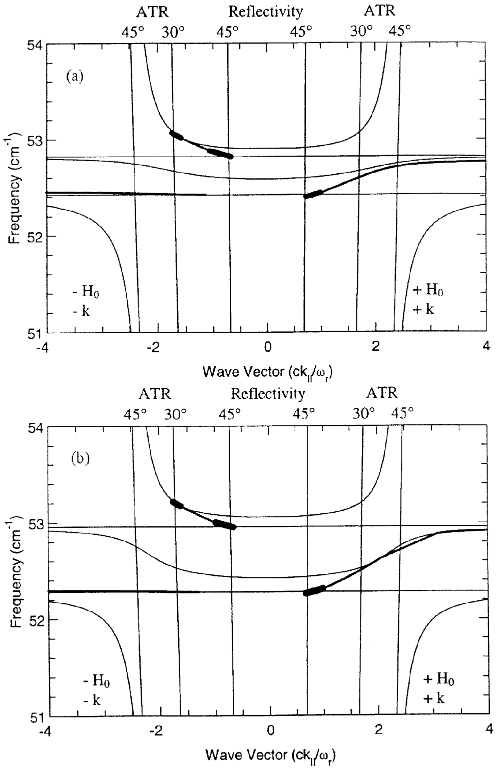

Fig. 3. Calculated magnetic polariton dispersion curves for FeF_2 at 1.6 K with applied static magnetic fields of (a) $H_0 = \pm 0.15$ T and (b) $H_0 = \pm 0.3$ T. The bulk polariton regions are bounded by the curved and horizontal thin lines. Also shown are surface modes (thick lines) and surface resonances (very thick lines). Scan lines, which are nearly vertical, are shown for reflectivity at 45° and ATR at 30 and 45°.

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