Observation of a soft mode and energy gaps during spontaneous spin reversal in $YbFeO_3$

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A soft mode has been discovered and identified in a spontaneous spin reversal in ytterbium orthoferrite. The energy gaps at the spin-flip boundaries have been measured.

The rare-earth orthoferrites are crystals with two magnetic subsystems, so that the nature of the soft mode of a magnetic resonance during the spin flips which have been observed in orthoferrites requires study.[1] In the orthoferrites which have been studied to date, $ErFeO_3$, $SmFeO_3$ (Ref. 2), $TmFeO_3$ (Ref. 3), and $HoFeO_3$ (Ref. 4), the soft mode at the Γ_2–Γ_4 spontaneous spin reversal is the σ mode of an antiferromagnetic resonance associated with oscillations of Fe^{3+} spins. The reason for this circumstance is that in these orthoferrites the role played by the rare-earth ions reduces to one of renormalizing the anisotropy constants of the iron subsystem and thus antiferromagnetic resonance frequencies. The inset in Fig. 1 shows the temperature dependence calculated for the soft antiferromagnetic resonance mode at the Γ_2–Γ_4

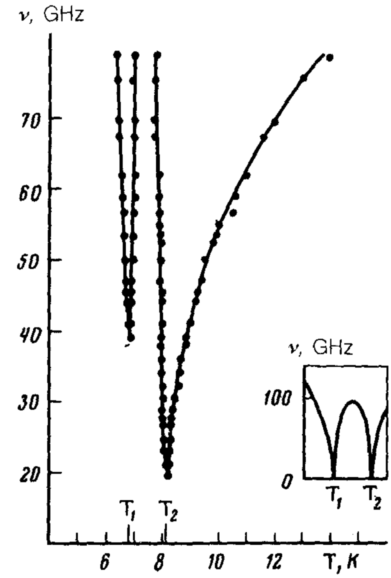

FIG. 1. Temperature dependence of the frequency of the soft magnetic resonance mode in $YbFeO_3$ near the Γ_2–Γ_4 spontaneous spin reversal. The inset shows the calculated[5] temperature dependence of the frequency of the σ antiferromagnetic resonance mode at the Γ_2–Γ_4 spin reversal.

spin reversal[5] without allowance for the effect of a magnetoelastic gap.[6] In the orthoferrites listed above, the spin flip occurs at temperatures ~ 100 K, so that it seems worthwhile to study the nature of the soft mode in $YbFeO_3$, in which the Γ_2–Γ_4 spin reversal occurs at considerably lower temperatures.[1]

Previous studies of $YbFeO_3$ in the submillimeter range did not reveal a magnetic resonance mode which softens upon a spin reversal.[7] In the study which we are reporting here, the crystal was studied in the millimeter range. The sample was a single-crystal sphere 0.8 mm in diameter; this dimension gets us away from the dielectric resonance over the entire working frequency range (14–79 GHz). The sample is placed at the center of a plunger which short-circuits a waveguide. The direction of the linearly polarized rf field **h** with respect to the crystal axes is chosen to excite the soft mode at the Γ_2–Γ_4 spin reversal: $\mathbf{h}\perp\mathbf{a}$ in the Γ_2 phase ($T < T_1$) and $\mathbf{h}\perp\mathbf{c}$ in the Γ_4 phase ($T > T_2$).[8] The absorption signal is recorded as the temperature is scanned at one of several fixed frequencies. The results are used to construct the temperature dependence of the magnetic resonance frequencies of $YbFeO_3$ near the Γ_2–Γ_4 spin reversal. The result is shown in Fig. 1.

The results of our experiments reveal a soft mode of a magnetic resonance and energy gaps at the points at which the spin flip begins and ends: $\nu(T_1) = 37.5 \pm 0.5$ GHz and $\nu(T_2) = 20.2 \pm 0.2$ GHz. The sizes of the energy gaps in orthoferrites at the Γ_2–Γ_4 spin reversal have been measured for the first time by a direct magnetic-resonance method. The values $T_1 = 6.85 \pm 0.03$ K and $T_2 = 8.15 \pm 0.05$ K were found from the positions of the minimum frequencies on the $\nu(T)$ curve (Fig. 1).

The absence of a softening of the σ antiferromagnetic resonance mode[7] is unambiguous evidence that the soft mode which we are seeing in the millimeter range is due to oscillations not of the Fe^{3+} spins but of the Yb^{3+} magnetic moments. Consequently, in contrast with other orthoferrites, in which the Γ_2–Γ_4 spin reorientation is accompanied by a softening of the antiferromagnetic resonance modes of the iron sublattices, it is a rare-earth mode which softens at the same spin reversal in the case $YbFeO_3$. This result means that the role played by the rare-earth subsystem near the spin flip in $TbFeO_3$ does not reduce to simply a renormalization of the anisotropy constants; in addition to the antiferromagnetic resonance modes, there are some weakly damped collective oscillations of Yd^{3+} magnetic moments, with a frequency that decreases near the points of spin reversal. As the temperature is raised, these oscillations acquire a relaxation nature, so that in other orthoferrities, with higher spin-flip temperatures, the only dynamic mode capable of softening is the σ antiferromagnetic resonance mode. The results of this study thus confirm the earlier suggestion[9] that there is a change in the dynamic properties of the rare-earth subsystem in an orthoferrite as the temperature is changed.

According to Ref. 10, the frequency of the soft mode does not vanish at the Γ_2–Γ_4 spin reversal because of a magnetoelastic interaction and a dipole contribution, and the values of the energy gaps at T_1 and T_2 are not the same. However, the calculation carried out to determine the values of $\nu(T_1)$ and $\nu(T_2)$ in that study dealt with the case of a high-temperature spin flip at which an antiferromagnetic resonance mode is softened. Further study is accordingly required to evaluate the contributions of various mechanisms to the formation of a gap at the Γ_2–Γ_4 spin reversal in $YbFeO_3$.

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