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On the Transverse Relaxation in YIG Doped with Yb

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A number of experimental facts supports the conjecture that a small fraction of Yb ions is situated in the anomalous octahedral sites of YIG (1 to 3). At the same time, an extremely anisotropic splitting of the ground state doublet of these ions is expected. To explain the well known low temperature resonance anomalies, the hypothesis was suggested that the transverse resonance relaxation may be effective for these anomalously situated ions. If shis explanation is true, certain non-linear effects should be connected with the mentioned resonance anomalies - as will be shown in the following comment.

During the ferromagnetic resonance, the admixture ions are exposed to an effective hf field which is considerably stronger than the external microwave field. If we assume that some Yb ions are approximately in resonance with the hf effective field according to the above hypothesis, then the saturation of these ions will occur at relatively weak external excitation. Consequently, the non-linear decrease in the relaxation rate will begin (4). This feature of the transverse resonance relaxation should lead to a specific instability in the ferromagnetic resonance which will be shown below.

At low temperatures and low concentrations of the admixture ions in YIG, the effective spin Hamiltonian $\vec{M}G\vec{S}$ may be used. It describes the interaction of an Yb ion (having the fictious spin $\vec{S}$) with the Fe ions system (having magnetization $\vec{M}$) by means of a certain tensor G. In the principal axes system of G, two different components of this tensor, namely $G_\perp$, $G_\parallel$, are considered and it is assumed that $G_\parallel \gg G_\perp$ (3). The effective field acting on $\vec{M}$ may be calculated from the spin Hamiltonian. Supposing the experimental arrangement with the dc magnetic field H_o and the perpendicular circularly polarized microwave field having the amplitude h, the following expression of the uniform precession amplitude μ_o is obtained from the equations of motion:

$$\mu_o = \frac{\gamma M h}{\gamma H_o - \omega + S + iW} \tag{1}$$

Supposing $G_\perp$, $G_\parallel$ to have the same values for all the considered ions, the dependence of S + iW on the uniform precession amplitude is given as follows:

$$S + iW = (S_o + iW_o)\left[1 + \frac{\frac{1}{2}A(\omega_{01})}{(\omega - \omega_{01})^2 + \left[(\gamma_o + \gamma_1)/2\right]^2}|\mu_o|^2\right]^{-1}. \tag{2}$$

Here $A(\omega_{01})$ depends on the lowest doublet splitting $\hbar\omega_{01}$ and on $G_\perp$, $G_\parallel$; γ_o, γ_1 represent the decay constants of the ground state and of the excited state respectively. - Taking the fluctuations of $G_\perp$ into account (3) (regarding $G_\parallel \gg G_\perp$, the corresponding fluctuations of $G_\parallel$ will be much less important) and using the Gaussian distribution for them, the following form of S + iW is obtained to a good approximation:

$$S + iW = S_o + iW_o\left[1 + \frac{2A(\omega)}{(\gamma_o + \gamma_1)^2}|\mu_o|^2\right]^{-1/2} \tag{3}$$

To demonstrate the unstable behaviour of the considered relaxation mechanism, the following special cases are discussed:

a) S + iW given by equation (2), $\omega = \gamma H_o$. Equation (1) together with equation (2) leads to a quadratic equation for $|\mu_o|^2$ having the real solution only for $h \leqq h_o$, where

$$h_o = \frac{|S_o + iW_o|}{\sqrt{2}\gamma M}\left[\frac{(\omega - \omega_{01})^2 + \left[(\gamma_o + \gamma_1)/2\right]^2}{A(\omega_{01})}\right]^{1/2}. \tag{4}$$

A finite $|\mu_o|^2$ corresponds to $h = h_o$, but $\lim_{h \to h_o} \frac{d}{dh^2}|\mu_o|^2 = \infty$.

b) S + iW given by equation (3), $\gamma H_o - \omega + S_o = 0$. Again, the critical field

$$h_c = \frac{W_o}{\gamma M}\frac{\gamma_o + \gamma_1}{\sqrt{2A(\omega)}} \tag{5}$$

is obtained, for which $\lim_{h \to h_c} |\mu_o|^2 = \infty$.

h_o and h_c are of the same order. Using Alben's estimate $|MG_\parallel| = 55\ \mathrm{cm}^{-1}$ (3) $\gamma_o + \gamma_1 = 10^9\ \mathrm{s}^{-1}$ (corresponding to the spin-magnon relaxation) and substituting $2W_o/\gamma = 100$ Oe, $h_c \approx 10^{-2}$ Oe is obtained for the direction of the considered resonance anomaly. However, the mentioned instabilities do not mean the decrease of $\Delta H_{eff} = 2W/\gamma$ to zero. In fact, the unstable increase of $|\mu_o|$ would imply the sudden lowering of ΔH_{eff} from the anomalous value $2 W_o/\gamma$ to a much smaller value coreesponding to the longitudinal relaxation at helium temperatures. Therefore, the importance of the transverse relaxation for the appearance of the resonance anomalies in YIG doped with Yb might be tested by investigation of these anomalies in dependence on the microwave field power.

References

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