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3-30-2003

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Accepted version. Published as a part of the *2003 IEEE International Magnetics Conference (INTERMAG)*. DOI.
Andrew Kunz was affiliated with Lawrence University at the time of publication.

2003 IEEE International Magnetics Conference (INTERMAG), (March 30-April 3, 2003). DOI.

Eigen Modes and Ferromagnetic Resonance Line Width of Inhomogeneous Thin Films

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Abstract:

In this paper, we describe modeling of the effects of magnetic inhomogeneity on ferromagnetic resonance line width using eigen mode analyses of inhomogeneous thin magnetic films.

As data rates approach and exceed 1 GHz in data storage and other magnetic devices. accurate measurements of magnetic damping are becoming increasingly important. Unfortunately, measurements of damping by ferromagnetic resonance are complicated by the presence of inhomogeneity. In this paper, We describe modeling of the effects of magnetic inhomogeneity on ferromagnetic resonance line width using cigenmode analyses of inhomogeneous thin magnetic films.

We start with a spin wave Hamiltonian identical to the one used in two-magnon calculations of inhomogeneous FMR line broadening [1]–[2][3],

$$E = \sum_k \omega(k) a_k^* a_k + \sum_{k,k'} (A_{k,k'} a_k^* a_{k'} + h.c.) \quad (1)$$

Here $\omega(k)$ is the magnon dispersion relation that incorporates the magnetostatic and exchange interactions, a_k^* and a_k are the rnagnon creation and annihilation operators, and the $\Lambda_{k,k'}$ terms arise from inhomogeneity. The inhomogeneity is modeled as an applied field $H_p(\boldsymbol{r})$ added to a uniform applied field, where $H_p(\boldsymbol{r})$ varies from grain to grain in Voronoi polygon “microstructures” with various typical grain sizes. In contrast to the two rnagnon model where $A_{k,k'}$ is treated as a perturbation we diagonalize the Hamiltonian for a few thousand low k spin wave modes to obtain the eigenmodes and eigenfrequencies of the perturbed film.[4] We then calculate the FMR spectrum as a superposition of the resonances due to each eigenmode.

We find that for small grain sizes, the eigenmode calculation is in good agreement with the two-magnon model, but for large grain sizes, the resonances become localized, and the spectrum is in good agreement with a local resonance model, The characteristic grain size D for this transition is approximately the distance required for a spin wave to experience a phase shift of π in a grain with perturbation field H_p or,

$$\frac{\partial k}{\partial H} |_{\omega} \langle H_p \rangle_{\mathrm{m_k}} D = \frac{2(H_p)_{\mathrm{m}s}}{M_s d} D = \pi(\mathrm{S.I}) \quad (2)$$

For example, in a $d = 3$ nm thick film of Permalloy with perturbation fields on the order of 5 mT. the characteristic length scale is approximately 1 µm. Despite the fact that local resonance models ignore exchange and magnetostatic interactions, they have provided good descriptions of experimental data in some cases [5]–[6].

The nature of an inhomogeneously broadended FMR spectrum according to the eigenmode analysis is a superposition of resonances with a distribution of resonance frequencies.

This picture is very different from the two magnon model picture of a uniform precession mode with increased damping.

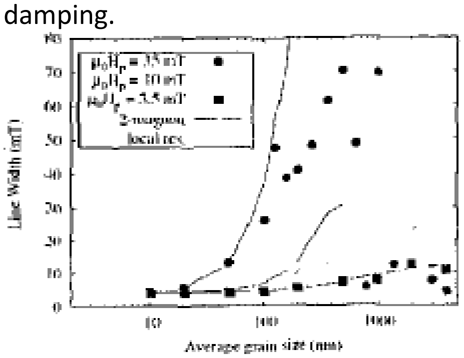

Figure 1. Peak-to-peak FMR line width for a 3 nm thick film of permalloy at 10 ghz calculated as a function of grain size for three values of the RMS perturbation field. H_p. Line width values from the two-magnon model and the local resonance model values are also plotted for each value of H_p. Low line width values at larger grain sizes occur when local resonance produces both the maximum and minimum FMR signal values.

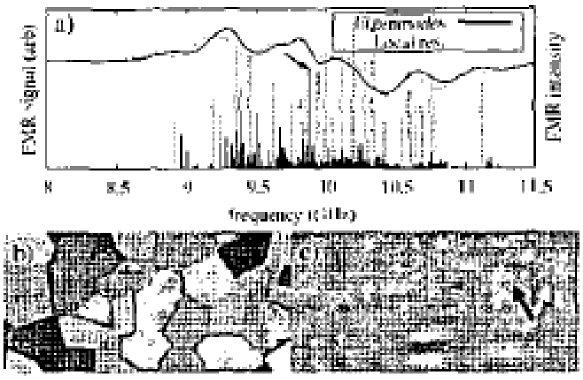

Figure 2. Details of the eigenmode analysis at a grain size of 1400 nm and $H_p = 10.6$.mT. a) FMR derivative signals (lines) calculated from eigenmode intensities and eigenfrequencies (solid spikes) and from grain area and. local applied field (dashed spikes). b) Half of the grain structure and c) the corresponding half of a gray scale map of the dynamic magnetization pattern corresponding to the eigenmode indicated by the arrow in a). Localization confines the dynamic magnetization mostly to two grains.

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