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1. X-RAY DETECTED MAGNETIC RESONANCE IN FERROMAGNETIC FILMS

X-ray Detected Magnetic Resonance (XDMR) is a novel spectroscopy[1,2] in which ***element selective*** X-ray Magnetic Circular Dichroism (XMCD) is used to probe the resonant precession of the magnetization caused by a strong microwave pump field $\mathbf{h_1}$ perpendicular to the static bias field $\mathbf{H_0}$. As illustrated with Figure 1, two different geometries can be envisaged to probe the precession dynamics.

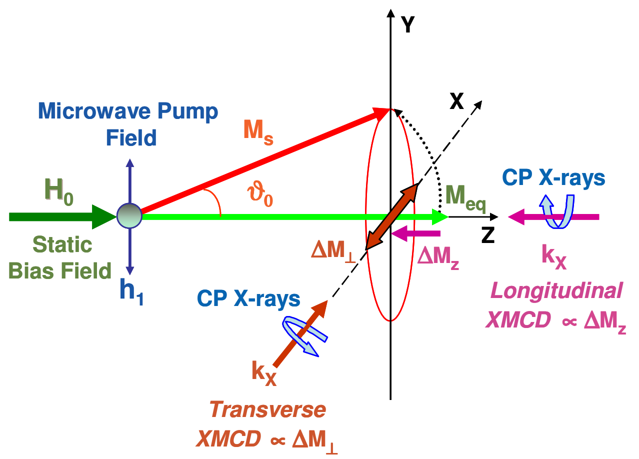

Figure 1

In the *longitudinal* geometry[1], the wavevector $\mathbf{k_x}(\parallel)$ of the incident circularly polarized X-rays is parallel to $\mathbf{H_0}$. The precession induces a steady-state change $\Delta M_\mathbf{z}$ of the magnetization probed by XMCD. The XDMR signal is then a 2^{nd} order effect proportional to the microwave power and that probes how fast the damping torque drives the magnetization **M** back to $\mathbf{M_{eq}}$.

In the *transverse* geometry[1], the wavevector $\mathbf{k_x}(\perp)$ of the X-rays is perpendicular to both $\mathbf{H_0}$ and the microwave pump field $\mathbf{h_1}$. XMCD then probes the transverse component of the magnetization $\mathbf{\Delta M_\perp}$ which oscillates at the microwave resonance frequency. The detection of this 1rst order effect, however, requires a very special instrumentation[1].

The information which is most easily accessible from *longitudinal* XDMR experiments is the (*apparent*) opening angle of precession ϑ_0 that can be obtained from[1,2] : $\Delta\sigma_{XDMR}\ (k_{//})/\Delta\sigma_{XMCD}\ (k_{//}) \approx -1/2\ \tan^2\vartheta_0$. Following Bloembergen & Wang[3], $\tan\vartheta_0$ could also be related to the longitudinal (T_1) and transverse (T_2) relaxation times since, at resonance and far from saturation, one has: $\tan^2\vartheta_0 \approx 1/2\ [\gamma h_1]^2\ T_1 T_2$. Unfortunately,

it is not a trivial task to determine h_1 accurately enough in an XDMR experiment and it is therefore not straightforward to access to a reliable estimation of the product T_1T_2. One should also keep in mind that the two relaxation times are related by some condition of the type: $(T_2)^{-1} = (2T_1)^{-1} + (T_D)^{-1}$ in which T_D would encompass all processes decreasing the coherence of the precessing magnetization (e.g. magnon scattering). It would be therefore very important to try to access to independent determinations of T_1 and T_2.

2. TOWARDS EXPERIMENTAL DETERMINATION OF T_1

It was the aim of project MI-875 to explore how far our measurements of $\tan^2\vartheta_0$ in the *longitudinal* geometry could yield more reliable information on the precession dynamics and relaxation processes. Obviously, what makes comparisons between different XDMR experiments (and samples) complicated is the fact that the effective pump field h_1 does not simply depend on the incident microwave power but varies with numerous parameters affecting the resonance conditions. To overcome these difficulties, we proposed a two step strategy: (i) incline the sample at the *magic angle* ($\beta = 54.74°$) in order to minimize the *foldover* distortion[2] of the resonance lineshapes at high pumping power; (ii) use standard FMR spectra to develop an independent calibration procedure allowing us to determine h_1, e.g. using the characteristic *foldover threshold* that can be predicted from analytical formulations[2].

XDMR spectra of a high quality YIG/GGG thin film rotated at the magic angle were recorded both in the *transverse* and in the *longitudinal* geometries. In the *transverse* geometry where one could benefit of a higher sensitivity, we produced clear evidence that slightly asymmetrical but narrow resonance linewidths ($\Delta H < 7.5$ Oe) could be obtained at high pumping power due to the minimization of the uniaxial anisotropy that is the main cause of foldover effect in YIG thin films. Unfortunately, in the *longitudinal* geometry, the price to be paid for rotating the film at the magic angle was a quite substantial loss of sensitivity (*ca.* 12 dB): the XDMR amplitude peaked at only -92 dBV instead of -80 dBV when the bias field H_0 was perpendicular to the film. It seems that the primary cause of such a loss of sensitivity is to be found in a significant lowering of Suhl's 2nd order instability threshold (i.e. two-magnon annihilation processes) which is associated with a premature saturation of the uniform precession mode.

On the other hand, our attempts to establish a calibration method using standard FMR spectra proved to be finally inconclusive since h_1 also depends on the geometry of the sample: no *foldover* threshold could be measured anymore for a film rotated at the magic angle. This failure which we had not anticipated stimulated us to explore a totally different approach which looks promising for determining T_1 in the longitudinal geometry. It consists in analyzing the *response* of the precessing magnetization to a *high frequency* amplitude modulation of the microwave power. Typically, in Bloch-Bloembergen approach, the relaxation processes should contribute to the existence of an additional phase-shift at the modulation frequency ω_{AM}:

$$\tan \Delta\Phi_{AM} = -\,\omega_{AM}\, T_1 \{ \; (1 - \xi^2 T_1T_2)[1 + T_2/2T_1] + 1/2\, (\omega_{AM})^2\, T_1T_2)[1 + T_2/2T_1] + \ldots\} \qquad (1)$$

in which $\xi = 1/2\ \gamma h_1$ now contributes only as a 2nd order corrective term. For our test sample, *i.e.* the YIG/GGG thin film rotated at the magic angle, we were able to detect the following phase-shifts: $\Delta\Phi_{AM} = 4.1°$ at a modulation frequency $F_{AM} = 71.0$ kHz ; $\Delta\Phi_{AM} = 7.9°$ at a modulation frequency $F_{AM} = 142.0$ kHz . Then, one is led to : $T_1 \approx 80$ ns if we assume $T_2 \approx 2T_1$ as in the Landau-Lifschitz-Gilbert damping model.

Since this measurement was performed at the iron K-edge, this would be the first direct, element-selective measurement of the Orbit – Lattice relaxation time. Further work is in progress to explore the whole potentiality of the method which is a peculiar adaptation of a technique known in Optics as *Phase Fluorimetry.*

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