ESRF	**Experiment title:** *X-RAY DETECTION OF MAGNETOELASTIC WAVES EXCITED UNDER OBLIQUE PARALLEL PUMPING*	**Experiment number:** **HE-3564**
Beamline: **ID-12**	**Date of experiment:** from: 30-MAR-2011 to: 04-APR-2011	**Date of report:** 01-MAR-2012
Shifts: **18**	**Local contact(s):** **A. ROGALEV and F. WILHELM**	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

José GOULON[1*], *Andrei* ROGALEV[1*], *Fabrice* WILHELM[1*], *Gérard* GOUJON[1*], *Jamal* BEN YOUSSEF [2]

[1] European Synchrotron Radiation Facility (ESRF), B.P. 220, F-38043 Grenoble Cedex

[2] Laboratoire de Magnétisme de Bretagne, CNRS FRE 2697, UFR Sciences et Techniques, F-29328 Brest Cedex , France

1. IN-PLANE & OBLIQUE PARALLEL PUMPING GEOMETRIES

Microwave *Parallel Pumping* (PP) has long been used for the parametric excitation of exchange spin waves under *non-linear* coupling processes [1-6]. When the microwave pump field $\mathbf{h_p}$ is parallel to the equilibrium magnetization $\mathbf{M}_{eq}$, no uniform precession mode ($\mathbf{k}$ = 0) can be excited but Schlömann [2a,2b] pointed out that spin waves ($\mathbf{k} \neq 0$) could be resonantly excited at half the pumping frequency (½ ω_p) due to the *elliptical* precession of thermaly activated magnons. For YIG thin films, the latter requirements are most easily satisfied for *in-plane* magnetization with $\mathbf{h_p} \parallel \mathbf{H_0}$ (Fig.1).

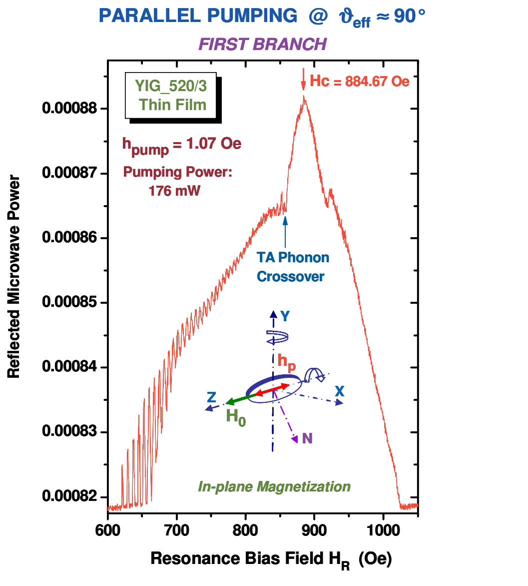

Fig. 1 PP microwave absorption spectrum of a YIG thin film recorded using a special microwave TE_{102} cavity designed to satisfy the requirement: $\mathbf{h_p} \parallel \mathbf{H_0} \perp \mathbf{N}$. Note the superstructure of narrow exchange-driven spin waves resonances [3].

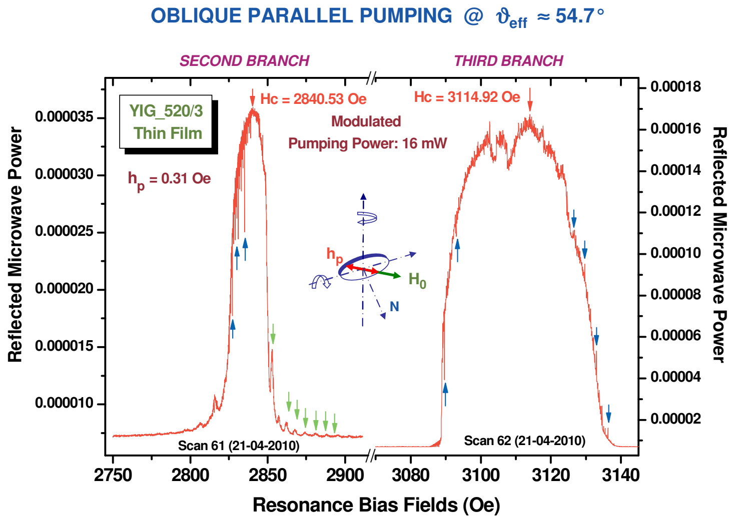

Fig. 2 In oblique PP experiments, the condition $\mathbf{h_p} \parallel \mathbf{H}_0$ is preserved but neither $\mathbf{H}_0$ nor $\mathbf{h_p}$ are parallel to the *effective* field $\mathbf{H}_{eff}$ of precession. Then additional branches can be observed at higher field. Such branches may exhibit a dense superstructure of extremely narrow resonances that could be assigned to magnetoelastic waves [6].

In *oblique* PP, *i.e.* when $\mathbf{H_0}$ is slightly inclined with respect to the film plane, there is still a weak (low-field) branch due to the parametric excitation of spin waves, but one or even two additional branches can be detected at higher resonance bias fields (Fig.2). The observation of a FMR-like branch indicates that either the *instantaneous* precession axis is not strictly parallel to the external field $\mathbf{H_0}$, or that the pump field $\mathbf{h_p}$ is not itself uniform inside the resonant cavity [1] . The origin of the 3^{rd} branch is not yet fully understood. On the low-field side of the 1rst branch, on may detect a very dense superstructure assigned to standing wave resonances of exchange spin-waves since the peak spacing is $\propto$ $[H_c - H_{bias}]^{1/2}$. Our ultimate goal was to check whether we could detect any XDMR signal associated with the microwave absorption due to this first branch and its nicely resolved superstructure.

2. DETECTION OF A VERY WEAK XDMR SIGNAL IN THE FIRST BRANCH

In the case of a high quality yttriium iron garnet (**1** = YIG) thin film, our powerful superheterodyne detection readout electronics allowed us to collect a whole series of XDMR spectra at the Fe K-edge but only for the second branch. These spectra, which were recorded in the oblique parallel pumping mode but in transverse detection geometry (TRD), nicely reproduced the expected magnetoelastic superstructure. Unfortunately, within a detection limit decreased by 4 orders of magnitude compared to the 2^{nd} branch, no XDMR signal could be measured in the 1rst branch in the TRD geometry. In an ultimate effort, we tried to detect a signal using the longitudinal detection geometry (LOD) as sketched in Fig. 3A.

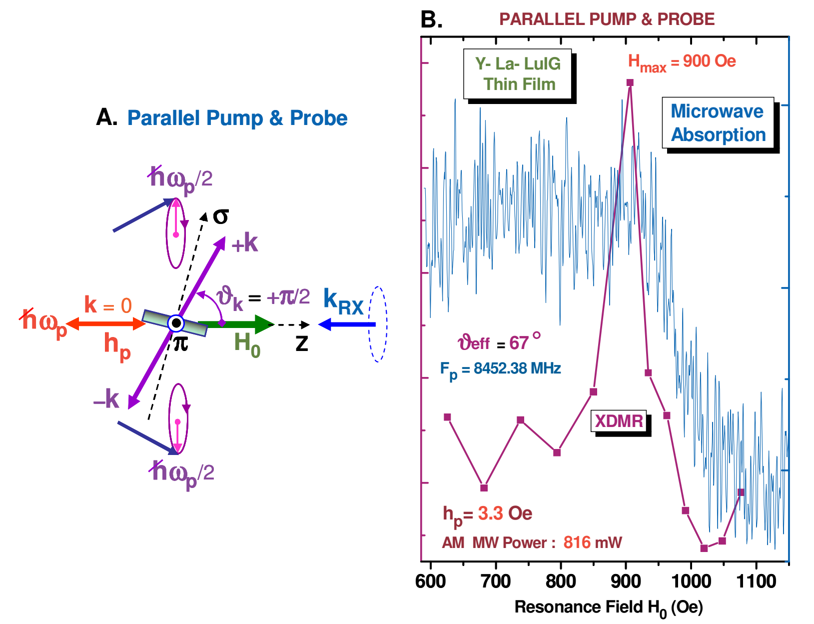

Fig. 3A Parallel Pumping combined with Longitudinal detection geometry [5].
Fig. 3B XDMR signal of the first banch measured at the Fe K-edge using film **2**.
The bias field $\mathbf{H_0}$ **was inclined by** ϑ_H = **54.7**° with respect to the normal to the film.

To further increase our chances of success, the experiments were carried with another film (**2** = Y-La-LuIG) in which the Y^{3+} cations were partly substituted with dia-magnetic rare earth cations (La^{3+}, Lu^{3+}): this is because film **2** had been previously shown to yield a strong XDMR signal in LOD geometry [4,5]. As illustrated with Fig. 3B, we finally succeeded in measuring a very weak XDMR signal at the Fe K-edge which is peaking exactly at the maximum of the microwave absorption of the first branch. In contrast with the microwave absorption, the XDMR spectrum seems to exhibit a very sharp peak and decreases very rapidly at low bias field. Note that this experiment was carried out under a very high pumping power of 816 mW, *i.e.* under conditions where no magnetoeleastic superstructure could be anymore resolved in the microwave absorption spectrum [5,6].

It is a clear advantage of the steady state signal $\propto$ m_Z measured in the LOD geometry that it is independent of the precession phase so that the contributions of the two nonuniform coupled modes (**k**, **–k**) cannot cancel each other. The observation of only a sharp line peaking very near H_C would support our interpretation that dipole-dipole rather than exchange interactions are at the origin of the nonuniform coupled modes that are excited. This does not look too surprising given that the XDMR signal measured at the Fe K-edge probes the existence of coupled non uniform modes of precession of orbital magnetization components which cannot be directly driven by exchange interactions [5,6].

REFERENCES

[1] A.G. Gurevich, G.A. Melkov: *Magnetization Oscillations and Waves*, CRC Press Boca Raton, Inc. (1996) chapt. 10.
[2a] E. Schlömann, *J. Appl. Phys.* **33** 527-537 (1962) ; [2b] J. Phys. Soc. Jpn, **17** Suppl. B-I 406-410 (1962).
[3] W. Jantz, J. Schneider, B. Andlauer, *Sol. State Comm.* **10** 937-940 (1972).
[4] J. Goulon *et al. XDMR of YIG films in the nonlinear regime of spin waves*, *J. Magn. Magn. Mater.* **322** 2308-2329 (2010)
[5] J. Goulon *et al XDMR: a unique probe of the precession dynamics of orbital magnetization components,* *Internat. J. Molecular Sciences* **12** 8797-8835 (2011) *Invited paper by the Editor (E. Kliger)*
[6] J. Goulon *et al XDMR of YIG thin film \under Tangential & Oblique Parallel Pumping* *Finalized manuscript to be submitted to J. Magn. Magn. Mater.*