ESRF	**Experiment title:** ***INDUCED MAGNETISM IN BISMUTH SUBSTITUTED IRON GARNET THIN FILMS***	**Experiment number:** **HE-2119**
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1. MAGNETIC PROPERTIES OF Bi-SUBSTiTUTED IRON GARNET THIN FILMS

High quality Bi substituted (RE-Y)IG films with RE = Lu, La...were grown at the *Laboratoire de Magnétisme de Bretagne* (Brest) using Liquid Phase Epitaxy (LPE) on carefully oriented GGG substrates[1]. Bi-Lu-YIG films represent a class of materials of outstanding technological importance, not anymore for bubble memories but for THz optical modulation[2,3] and monolithic microwave integrated circuits (MMIC) devices[4]. With a closed shell structure Bi^{3+} cations are expected to be diamagnetic, but they strongly affect the magnetic and magnetooptical properties of those films combining a large Faraday rotation ($\theta_F \approx 1.2°/\mu m$), *in-plane* magnetic anisotropy and ultra-high frequency response. Bi-substituted (RE-Y)IG films were also found to exhibit a "*giant"* magnetoelectric (ME) rotation linear with the applied electric field[5]. Simple considerations regarding symmetry lowering[6] in a film grown on a cubic m3m GGG substrate suggest that the true point group could then be 3m, 4mm or only m depending on whether the film is grown along the [111] , [001] or [210] directions. We are not aware yet of any determination of the true magnetic groups of Bi-substituted iron garnet films on any particular GGG substrate.

XMCD did appear to us as an attractive tool to elucidate the long pending question of the existence of *induced* magnetic moments at the sites of a variety of important "*diamagnetic*" cations (Y^{3+}, La^{3+}, Lu^{3+}, Bi^{3+}). Moreover, the XMCD sum rules add to the inherent element/edge selectivity of X-ray absorption spectroscopy some valuable potentiality to discriminate between orbital and spin moments. It was therefore the main objective of proposal HE-2119 to carry out detailed XMCD studies on series of iron garnet films but we also envisaged to complement ultimately this work on collecting *X-ray Magneto-Electric Linear Dichroism* (XMELD) spectra on selected films. Unfortunately, no beamtime was left free for such delicate experiments.

2. X-RAY DICHROISM STUDIES OF SUBSTITUTED IRON GARNET FILMS

In this report, we shall focus on partial results collected on three films: **1** = unsubstituted YIG ($Y_3Fe_5O_{12}$) ; **2** = {Y,La,Lu}IG ($Y_{1.3}La_{0.47}Lu_{1.3}\ Fe_{4.84}\ O_{12}$) ; **3** = {Y,Bi}IG ($Y_{1.69}Bi_{1.31}Fe_{4.9}Ga_{0.1}\ O_{12}$). Both X-ray circular and linear magnetic dichroisms (*i.e.* XMCD & XMLD) spectra were measured at the Fe K-edge. High quality XMCD data were collected in the fluorescece excitation mode at the spin-orbit split Y, La, Lu $L_{2,3}$-edges. After proper

corrections for fluorescence re-absorption and for variable circular polarization rates, we could make use of the *differential* formulation of the magneto-optical sum rules to resolve the 4d- or 5d-projected ***orbital*** or ***spin*** DOS , *i.e.* the differential operators ℓ_z and $2s_z$ whose spectra are reproduced in Figures 2 and 3 which produce clear evidence that the Y 4d states and the La, Lu 5d states are strongly spin-polarized even though the corresponding integral spin moments cancel out : $\langle s_z \rangle_d \leq 0.01\mu_B$.

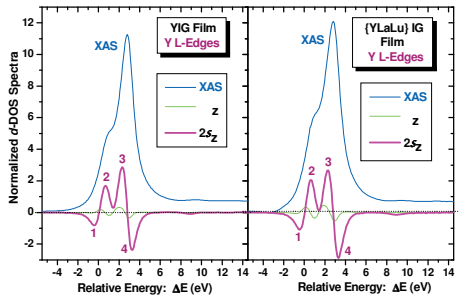

Figure 1

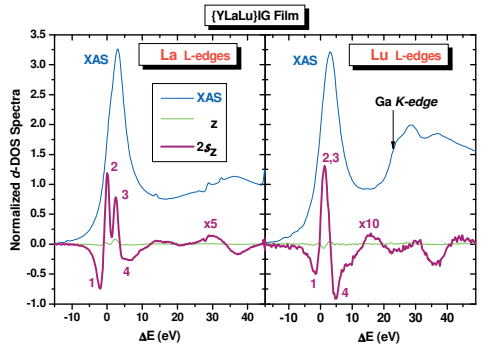

Figure 2

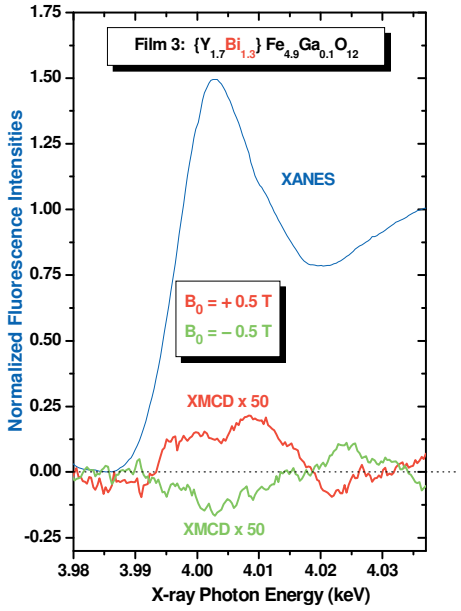

Figure 3

Figure 1

Magnetically polarized ***Orbital*** & ***Spin*** and 4d-DOS of yttrium in films **1** and **2** respectively.

Figure 2

Magnetically polarized ***Orbital*** & ***Spin*** and 5d-DOS of Lanthanum & Lutetium in film **2** .

Figure 3

Normalized XANES & XMCD spectra of film **3** recorded at the Bi M_1-edge. As for a K-edge, XMCD is entirely due to orbital magnetization components

The experiments were much more challenging at the Bi M_1-edge but nearly hopeless at the Bi $M_{4,5}$-edges where the circular polarization rates of the monochromatic X-ray beam are vanishingly small. Nevertheless, the unambiguous detection of a weak XMCD signal at the Bi M_1-edge established for the first time the existence of a weak ***orbital*** magnetic component involving the 6p states of Bi. Recall that a careful NMR study[7] concluded that the internal field at the ^{209}Bi nuclei was too high to be explained only by the dipole field of the ferric ions and suggested that *localized* magnetic moments *might* exist at the Bi sites. Difference spectra also revealed subtle changes[1] in the Fe K-edge XMCD spectra of films **1** and **3**.

Interestingly, weak signal of *natural* X-ray linear dichroism were systematically observed at the Fe K-edge with all iron garnet films as well as with a bulk YIG crystal cut parallel to the (111) planes: this proved that, at room temperature, the crystal cannot satisfy all requirements of perfect cubic symmetry, crystal distortions preserving at best a trigonal symmetry (R3 or R3m). A very weak -but perfectly reproducible- XMLD signal[1] was also measured in the Fe K-edge prepeak of the XANES spectrum of YIG: this signal revealed the presence of a tiny electric quadrupole moment in the ground state charge distribution of the iron atoms in YIG.

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