	Experiment title: Uranium-3d and -4f multilayers: investigation by XMCD	**Experiment number**: **HE-1781**
Beamline: ID12	**Date of experiment**: from: 26/10/2004 to: 02/11/2004	**Date of report**: 7 October 2005
Shifts: 18	**Local contact(s)**: Wilhelm Fabrice Jaouen Nicolas Rogalev Andrei	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Prof. STIRLING William G.*, E.S.R.F. Grenoble, France
Dr. BROWN Simon *, E.S.R.F. Grenoble, France
Dr. LANDER Gerry, ITU Karlsruhe, Germany
Dr. LANGRIDGE Sean, I.S.I.S. Didcot, United Kingdom
Dr. WELLS M., Oxford University, United Kingdom
Dr. WARD Roger, Oxford University, United Kingdom
SPRINGELL Ross *, University College London, United Kingdom

Report:

Multilayers composed of 5*f* uranium and a 3*d/4f* metal provide the unique combination of a "non-magnetic" element possessing a large spin-orbit coupling with a strongly ferromagnetic 3*d* transition metal or 4*f* rare-earth. The strong electronic hybridization effects between the extended 5*f* states and the strongly magnetic delocalized 3*d* states of the transition metal or localized 4*f* states of the rare-earth metal can give rise to specific magnetic properties (such as enhanced magneto-optical and transport effects) that are of interest from both of fundamental and applied points of view.

In the case of Fe/U multilayers, we have already demonstrated in our previous measurements (HE-1465), that a strong Fe-U hybridization at the interface leads to a polarization accross the uranium layers. We have used XMCD to study the magnetic polarization of the 5*f*-shell of Uranium (via the $M_{4,5}$-edges) and the orbital magnetism of the 4*p*-shell of Fe (via the K-edge) in Uranium/Iron multilayers. Several important conclusions regarding the induced magnetism of the U atoms have been drawn thanks to the element and shell selectivity of the XMCD technique (see report of HE-1565). During this beamtime, as proposed, we have completed our work by performing XMCD at the $M_{5,4}$-edges of U and K-edge of Fe for U/Fe multilayer samples with very thin uranium layers ($U_{9Å}/Fe_{34Å}$) and with an intermediate iron thickness ($U_{23Å}/Fe_{17Å}$) compared to those studied previously.

In Fig. 1, a clear XMCD signal recorded at 10K and under 0.5Tesla at the U $M_{4,5}$-edges induced by the magnetic Fe layers is presented, with a strong dependence on both U and Fe thickness. For nearly the same Fe thickness (~30Å), as the thickness of U increases from 9Å to 26Å, the XMCD signal of the averaged U layers decreases. This demonstrates that the U atoms do not carry a constant induced moment within the layers (constant induced magnetization profile). It suggests that the U atoms located at the interface carry a larger induced 5*f* magnetic polarization than those within the layers. In Fig.2 the U 5*f* spin and orbital moment is plotted as a function of the U thickness. At the interfaces, the maximum value of the U 5*f* magnetic moment is 0.18μ_B/atom and -0.09μ_B/atom respectively for the orbital and spin components. The origin of the polarization of the U atoms is the Fe(3*d*)/U(5*f*)-U(6*d*) hybridization. By considering different U thicknesses and considering a simple model based on non-interacting layers, we have extracted a U 5*f* polarization profile which is found to decrease exponentially from the interface to the centre of the U layers, accompanied by a long-period oscillation . Additionally, using the XMCD sum-rules, we find that both spin and orbital induced magnetization profiles behave in a similar manner.

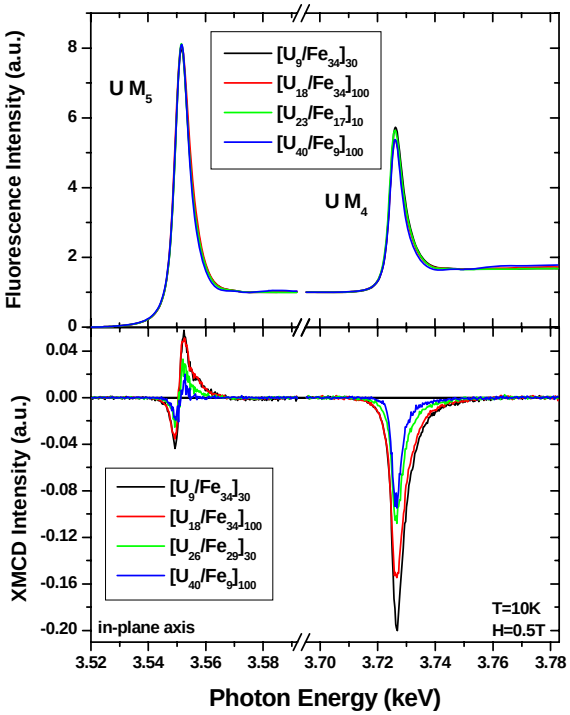

Fig. 1: U $M_{4,5}$-edges XAS and XMCD spectra recorded at 5K and under 0.5Tesla at grazing incidence (15°) for U/Fe multilayers with different composition. All spectra have been corrected for self-absorption effects.

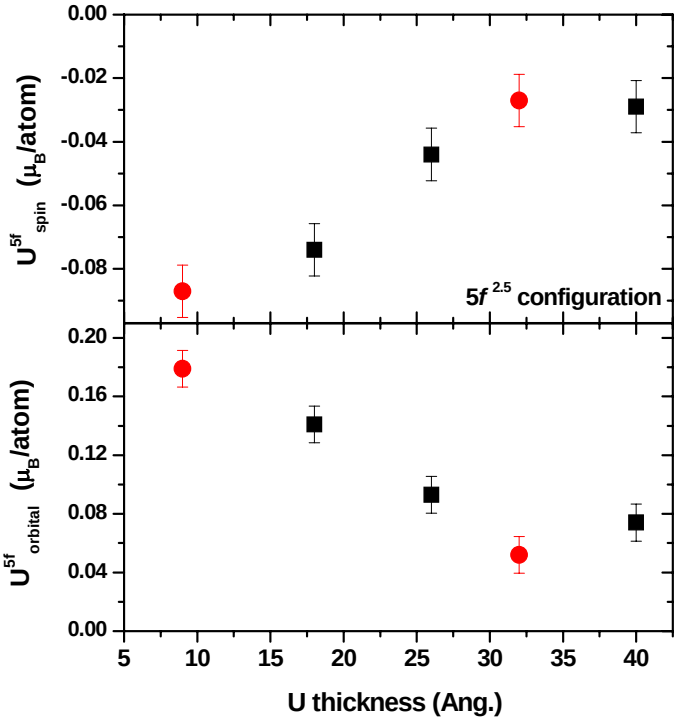

Fig. 2: U 5*f* spin and orbital magnetic moment as a function of U thickness determined using the sun-rules applied at the U $M_{4,5}$-edges. We have assumed a mixed configuration $5f^{2.5}$ ($5f^2/5f^3$).

In the case of U/Gd, we attempted XMCD measurements for multilayers with different layer thicknesses ($U_{26Å}/Gd_{76Å}$and $U_{39Å}/Gd_{20Å}$) at both U $M_{4,5}$-edges (Fig.3) and the Gd $L_{3,2}$-edges (Fig.4). The samples were measured at 5K, using magnetic fields up to 5 Tesla to ensure complete magnetic saturation. Fig. 3 presents preliminary XMCD spectra measured at the $M_{4,5}$-edges of U in U/Gd multilayers. These preliminary results show that the U 5f states are magnetically polarized. In comparison to U/Fe multilayers (see Fig.1), much smaller XMCD signals are measured (~2%) despite the strong ferromagnetism of the Gd layers. Moreover, in U/Fe multilayers, the XMCD signal at the U M_5 edge has a typical dispersive-like spectral shape whereas the U M_4 XMCD signal is Lorentzian-like and the amplitude is up to 20% with respect to the edge jump. In U/Gd, the spectral shape of the XMCD signal at the M_4 edge is however completely different from that observed for U in U/Fe.

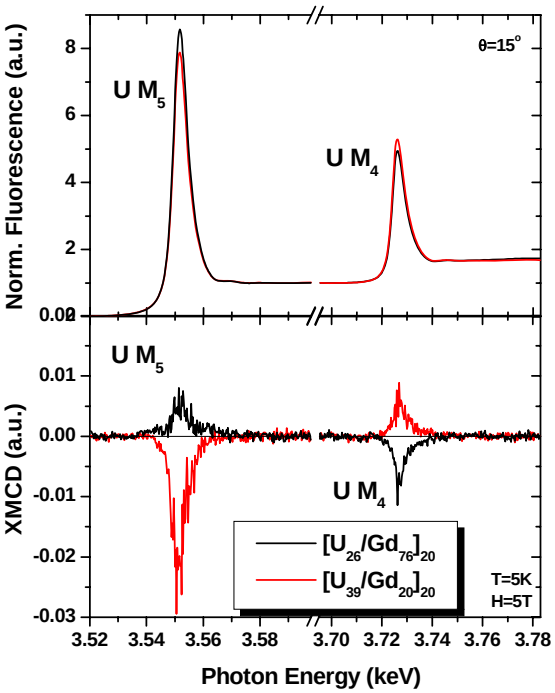

Fig. 3: U $M_{4,5}$-edges XAS and XMCD spectra recorded at 5K and under 0.5Tesla at grazing incidence (15°) for U/Gd multilayers with different composition. All spectra have been corrected for self-absorption effects.

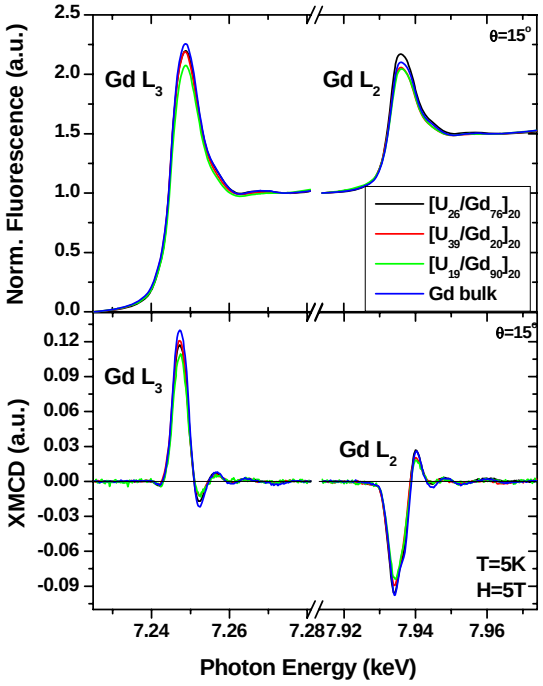

Fig. 4: Gd $L_{3,2}$-edges XAS and XMCD spectra recorded at 5K and under 0.5Tesla at grazing incidence (15°) for U/Gd multilayers with different composition. All spectra have been corrected for self-absorption effects.

This may mean that the U polarization mechanism has a different origin than for U/Fe multilayers. Moreover, depending on the thickness of U, the sign of the signal is inverted. From those observations, we suggest that the hybridization responsible for the small observed signals is the direct exchange via the 4f(Gd)/5f(U) hybridization which seems to be less efficient than the 3d(Fe)/5f(U) hybridization. These preliminary results show unambiguously that U 5*f* states are magnetically polarized; however we are not sure whether the observed XMCD signal at the U M-edges is induced by the applied field (i.e. paramagnetic moment) or induced via Gd (4f-5d) – U (5f) hybridization.

Further analysis of these data is in progress.