ESRF	**Experiment title:** Investigation of the ferromagnetic semiconductor SmN by X-ray magnetic circular dichroism	**Experiment number**: HE-2986
Beamline: ID08	**Date of experiment**: from: 1-5-2009 to: 4-5-2009 from: 30-9-2009 to: 3-10-2009	**Date of report**: 15-2-2010
Shifts: 2×9	**Local contact(s)**: Julio Criginski Cezar	*Received at ESRF:*

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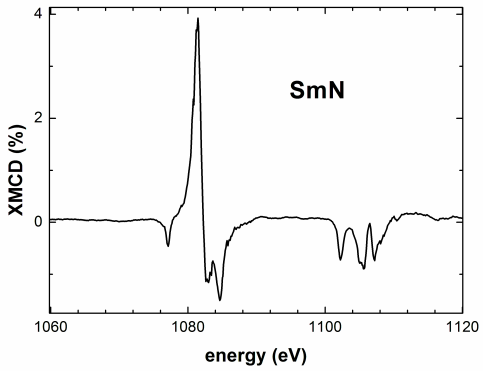
Report:

This 2009 programme at ESRF was aimed at determining the spin and orbital moments on the Sm 4*f* and the N 2*p* shells in SmN. It is based on recent advances we have made in the successful film growth and passivation of stoichiometric rare-earth nitrides, a particularly rich collection of mostly ferromagnetic semiconductors [1]. Members of the series have properties that give them special promise in spintronics technology, though the currently-achieved low Curie temperatures may limit their value to demonstration devices. At the same time their simple structure and strongly localised 4*f* levels make them an excellent proving ground for theoretical treatments of strongly correlated materials, with the result that the recent literature on the topic is strongly biased toward theory [2].

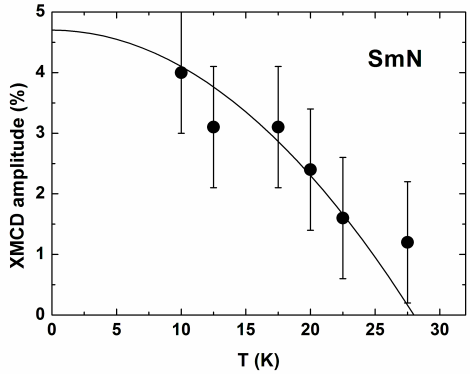
SmN has been a particularly difficult member of the series, with arguments even about whether it is ferro- or antiferro-magnetic. We have shown it to be ferromagnetic with a Curie temperature of 27 K, but with a surprisingly small moment of 0.03 μ_B. In the paramagnetic state it has a moment of 0.35 μ_B, a reduction below the free-ion moment that is quantitatively understood as arising from the crystal field, suplemented by a van Vleck contribution.[1] The small ferromagnetic moment is not at all understood, and it was to investigate that state that we proposed X-ray magnetic circular dichroism (XMCD) studies at the Sm $M_{4,5}$ and N K edges. The relatively low energy of these edges required beamline ID08.

We performed the measurements firstly in May, and although the session started promisingly there was a cryostat failure after a few hours. Despite that we were able to recover results at 80 and approximately 6 K by transferring liquid nitrogen or helium into the reservoir near the sample. The failure prompted a rescheduled session in October, when we managed to collect data over the full temperature range of interest. It was disappointing that the passivating layer required to prevent oxidation of SmN attenuated the TEY signal, introducing ≈5% noise in the Sm M-edge XMCD spectra and preventing accurate XMCD at the N K edge. Nonetheless we collected useful data shown in the figure below; these results are already included in an invited publication. The most important single inference from the

data is that the very small net moment lies parallel to the *orbital* moment of the 4*f* shell, raising the possibility of doping with Gd to engineer a strictly zero ferromagnetic moment. A similar doping has been accomplished in the metallic ferromagnetic $SmAl_2$ [3], but the importance here is that SmN can provide a *zero-fringe-field semiconducting* source of spin polarised electrons to be integrated in spintronics structures.



XMCD spectrum of SmN at 7K in 5T



Temperature variation of the XMCD amplitude

It is important to extend these studies to determine the temperature dependence of the orbital and spin moments in both the ferromagnetic and paramagnetic phases, but the capped films proved to be inappropriate for that study. The *in situ* preparation chamber on ID08 permits us to avoid this problem, for which we have made a proposal in the March 2010 round to ESRF. A study of the moments on the 5*d* shell will also be proposed, using beamline ID12. The 2*p* and 5*d* shells are important not only to determine the balance of moments among these shells, but also as a guide to the fundamental understanding of the indirect exchange via these shells in SmN.

Although it was not a part of the original proposal we also performed preliminary XMCD studies on EuN. This material is of even more theoretical interest, for we have recently demonstrated a ferromagnetism that is difficult to accommodate within the J=0 ground state of the Eu^{3+} ion. The very preliminary XMCD results are intriguing, showing a ferromagnetic signal that tracks the measured magnetic moment, but with the Eu^{2+} signature. That lies over a temperature-independent (van Vleck?) signal that appears to signal Eu^{3+}, but related to an admixture with the J=1 excited state.

In summary we have collected XMCD data on the RE M edges in SmN and EuN. The SmN data are already included in a submitted manuscript and the EuN data will be presented at the March Meeting of the American Physical society. We already have requests to share the EuN results with a theorist who read the March Meeting abstract. The data point clearly to improvements and extensions, and it is important to carry the studies forward with (1) improved S/N at the M edge and (2) N K-edge data using *in-situ* grown films and (3) determining the 5*d* moments with $L_{2,3}$-edge XMCD.

References

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