ESRF	**Experiment title:** Magnetic properties of GdN/SmN superlattices probed by XMCD at the $L_{2,3}$ edges of the rare earth	**Experiment number**: HE-3780
Beamline:	**Date of experiment**: from:13/6/12 to:19/6/12	**Date of report**: 21/8/2012
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Report:

Background to the study

This $L_{2,3}$ XAS/XMCD experiment was conceived to invesigate the magnetic state and exchange interactions in homogeneous epitaxial SmN and across SmN/GdN heterojunctions in a superlattice. These are systems both of fundamental interest for their strong correlations in relatively simple crystalline structures and of exploitation interest for their potential in prototype spintronic structures.[F. Natali et al, arXiv:1208.2410 (2012)] SmN is especially interesting for its ferromagnetic order (T_C = 27 K) with almost zero magnetic moment, a result of near cancellation between orbital and spin magnetic moments.[C. Meyer et al, Phys. Rev. B **78**, 174406 (2008)] This is exactly a regime in which the spin/orbital sensitivity and shell specificity of XMCD has a huge advantage in comparison to magnetic moment measurements, eg. our earlier studies by SQUID magnetometry.

Structured films are of special interest for device-like structures, though there are also many fundamental questions on which they can shed light. This particular pair, GdN and SmN, have strongly contrasting magnetic properties with potential as magnetoresistance memory elements; GdN has a huge moment and vanishingly small coercive field while SmN has a vanishingly small moment and enormous coercive field. The factor-of-200 contrast in the magnetic moments means that here even the best magnetometry has difficulty separating the Sm and Gd contributions, so that again XMCD is an essential ingredient in any investigation for its element-species selectivity.

Experiments performed

The films were thinner than the absorption length at the L-edge energy, so measurements were performed in the fluorescent-yield mode. XAS and XMCD spectra were collected initially at T = 15 K and B = 5 T, and followed also to higher temperature. The XMCD data in Figure 1 established directly that in homogeneous SmN it is the orbital moment that dominates in the near cancellation; the spin magnetic moment is directed antiparallel to the applied field. Significantly that situation was found both above and below the Curie temperature. It is in direct contradiction to an LSDA+U result showing a spin moment dominating in the ferromagnetic state. Note, however, that the cancellation is so complete that any calculation requires better than 1% accuracy in the individual conributions to the moment. Continuing with the homogeneous film we briefly investigated the hysteresis (Figure 2) to find complete agreement with our SQUID results.

The $L_{2,3}$-edges probe the 5*d* levels by the dipole interaction, so that the 4*f* polarisation is then probed only indirectly. However, there was found to be a sensible L_2 feature associated with quadrupolar $2p \rightarrow 4f$ transitions as well; this feature is not yet well represented by our modelling but still provides a comparison that demonstrates that the 5*d* alignment closely follows the 4*f*, as expected in the presence of their relatively strong exchange.

Results for the superlattice contrast strikingly with the homogeneous film of the previous paragraphs. Here the Sm spin moment aligns directly to the applied field, due to its strong exchange with the field-aligned Gd spin moments across the GdN/SmN interface. Thus the signs of the XMCD spectra (Fig. 1) are here of reversed sign to those in homogeneous SmN. Furthermore the field- and temperature-dependent Sm signal follows the GdN signal, retaining a ferromagnetic polarisation to a tempertature of over 50 K and a very small coercive field (Fig. 2), all characteristics of GdN. Unsurprisingly, then, any MRAM based on the pair will require exchange-blocking layers at the interface. We are currently applying for time to explore exactly the efficacy of blocking layers.

Finally we used a brief period at the end of our session to investigate a EuN film that had been grown with a large (~5%) concentration of nitrogen vacancies. This is a material which we speculated might be a diluted magnetic semiconductor (DMS), based on previous L- and M-edge XMCD at ESRF.[B.J. Ruck et al, Phys. Rev. B **83**, 17404 (2011)] We had observed a ferromagnetic behaviour but needed confirmation that it involved alignment of Eu^{3+} ions in the structure; that they provide the exchange among the vacancy-related divalent ions. The result of this experiment was very clear, indeed there is a strong alignment of trivalent ions, and they are involved in the ferromagnetism.

Overall, the beamtime was highly successful, with significant results obtained that will form the core of two publications (1. SmN XMCD and 2. interface exchange in a superlattice) and will provide a central contribution to a third (EuN as a DMS). All of the publications will be submitted to high impact factor international journals.

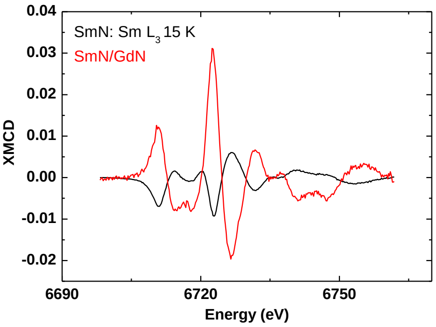

Figure 1. Reversed XMCD spectra in a homogeneous SmN (black) and the superlattice (red).

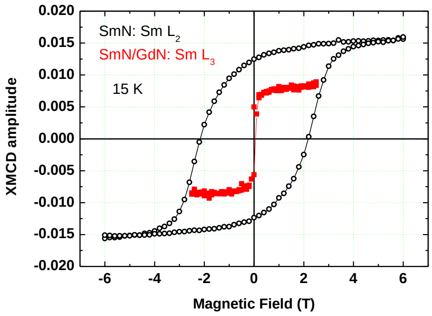

Figure 2. Comparison of Sm hysteresis in SmN (black) and a superlattice (red).