X Axis Title

ESRF	**Experiment title:** **Magnetic hysteresis of the Gd moments in GdN/Fe multilayers studied by hard X-ray magnetic circular dichroism**	**Experiment number**: HE-1397
Beamline:	**Date of experiment**: from: 20 November 2002 to: 26 November 2002	**Date of report**: 26. 02. 2003
Shifts: 21	**Local contact(s)**: Dr. Olivier MATHON	*Received at ESRF:*

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Report:

The experiments performed concern the magnetic interactions at the interfaces between two magnetically ordered thin metal films. A model system are Gd/Fe multilayers [1]. In a magnetic field, a variety of spin configurations appear due to the competition between the interfacial interaction and Zeeman energies. At low fields the magnetic structure is governed by the antiferromagnetic coupling at the interfaces of the two ferromagnets and represents an artificial ferrimagnet. The film with the larger moment is aligned parallel to the field (aligned phase). At higher fields the magnetic configuration resembles a spin-flop state, in which the magnetic moments of each layer make a different angle with respect to the applied field (twisted phase).

In the allocated beamtime we have studied the hysteresis curve of the Gd 5d-electron magnetisation in GdN/Fe multilayers by measuring XMCD at the Gd-L_2 edge (7929 eV). Fe was combined with the *ferromagnet GdN* instead with the originally proposed GdH_2 since after an initial check of the latter system we considered that with the nitride to be more interesting for this type of experiment. In fact, the macroscopic magnetisation of the multilayers had revealed that *the application of an external magnetic field permitted to orient the Fe and average GdN-layer magnetic moments parallel* at low temperature. Such orientation was never induced before in rare earth transition metal systems (including Gd/Fe and GdH_2/Fe) and was not known when we submitted our proposal (It was originally submitted in 02/01. Since the experiment then could not be carried out successfully due to technical problems with the beamline (see report on HE-1199) it was resubmitted in 02/02).

Why GdN? According to a recent theoretical prediction by ab initio calculations [2] this ferromagnet (T_C ~60 K) may be a half metal with complete spin polarisation of the charge carriers at the Fermi level. This makes it interesting for potential application in magnetoelectronics. Recently we succeeded in preparing high-quality thin films of GdN by N^+ plasma-assisted reactive sputtering [3]. They show good stoichiometry and the Curie temperature T_C of the bulk material. The electrical conduction is thermally activated down to T_C where a transition to metallic behaviour occurs. The GdN/Fe multilayers for the XMCD experiment were grown on Kapton foil to enable measurements in transmission mode. The Gd-L_2 hysteresis loops were recorded by using a variable external magnetic field from an electromagnet, oriented parallel to the beam and at glazing angle to the multilayer, and by a diamond a quarter-wave plate to reverse the helicity of the photons.

Magnetism of the multilayers is closely connected with the interfacial Gd-Fe interaction and the magnetic polarisation characteristics of the GdN interlayers. This is apparent in the temperature dependence of the Gd-L_2 XMCD amplitude measured in the remanent state of the multilayers in zero magnetic field (Fig. 1). The proximity to the high-T_C Fe (1024 K) enhances the magnetisation of low-T_C GdN at the interfaces considerably (see, e.g., the high dichroic signal at T_C of GdN). Ferromagnetic order in GdN prevails at least up to 300 K. From the dependence of the signal on the GdN-layer thickness the magnetically polarised region is estimated to be ~5 Å, which gives a measure of the spatial extent of the interlayer interaction.

In Fig. 2 we show, as an example, the Gd-L_2-edge XMCD hysteresis loops of a sample with 50 Å thick GdN sublayers in comparison with the global magnetisation curves at 2 different temperatures. At 20 K, the GdN- and Fe-layer magnetic moments are antialigned in a low magnetic field, with the Fe moment parallel to the field. This can be concluded from the sign of the XMCD signal. 2 features are remarkable: (i) The coercive fields of the Gd- and global magnetisation curves are different. This points to a complex magnetic structure in the multilayers, which varies with field and temperature. (ii) At 20 K, the XMCD signal changes its sign when the external field exceeds 2 kOe, indicating that the average Gd-5d moment is turned parallel to field and parallel to the Fe moment. The analysis of the multilayer magnetisation at different fields and temperatures reveals that reversal of the Gd magnetisation occurs inside the individual GdN sublayers. This reflects the relatively weak exchange interaction in GdN, as expected for a low-carrier system. The results for the samples with thinner GdN layers are consistent with this picture. Let us note that the beamtime available did not permit to perform XMCD hysteresis loops at the K edge of Fe, mainly because of the small signal at this threshold.

[1] see W. Hahn et al., Phys. Rev. B **52**, 16041 (1995) and references there in.
[2] W.R.L. Lambrecht, Phys. Rerv. B **62**, 13538 (2000).
[3] F. Leuenberger *et al.,* to be published.

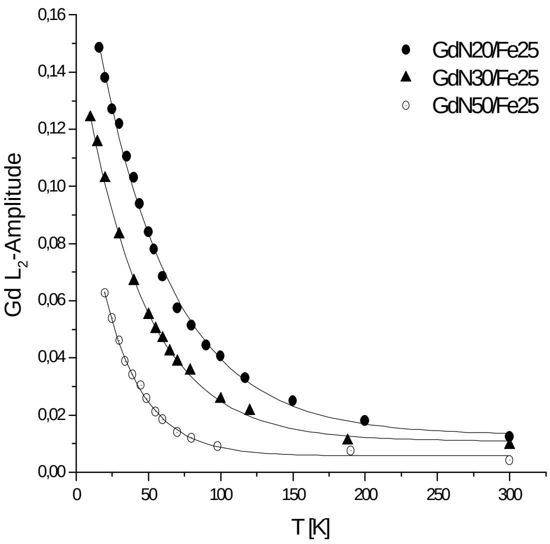

Fig.1 : Remanent Gd L_2 XMCD amplitude vs. temperature for three multilayers.

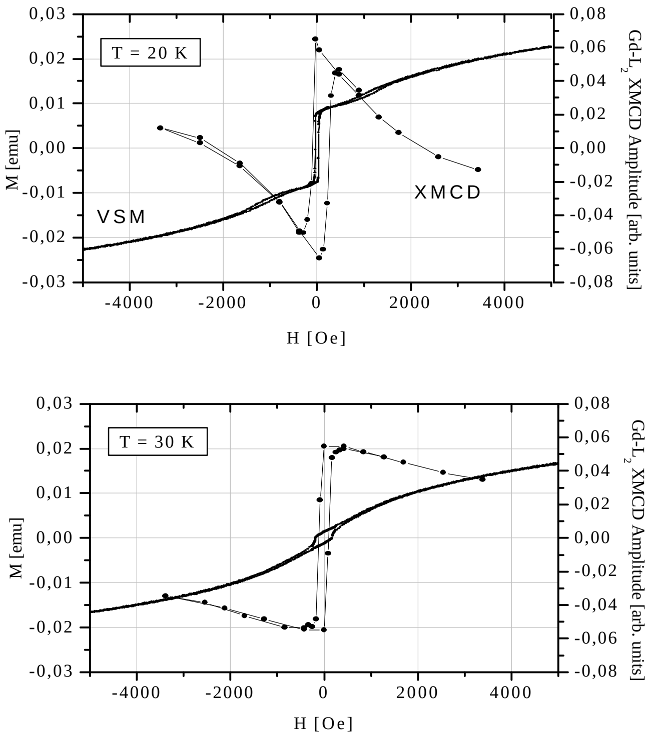

Fig.2 : Magnetisation curves (VSM and XMCD) of the multilayer [GdN50/Fe25]x52.