Experimental report

19/04/2016

Proposal: **5-54-179**

Council: 10/2014

Title: Spiral spin structures in GdN/NdN bilayers

Research area: Physics

This proposal is a new proposal

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Samples: NdN
GdN/NdN

Instrument	Requested days	Allocated days	From	To
D17	7	6	05/05/2015	11/05/2015

Abstract:

We will investigate the interlayer exchange in GdN/NdN bilayers and its influence on the spin spring structures in the two layers. The spin profiles are especially interesting for the opposing spin- and orbital- dominated magnetic moments, respectively, in GdN and NdN, spin profiles nucleated by the ferromagnetic Gd-Nd interface exchange. Such a spin-twisted structure has been signalled by our recent XMCD study of a related SmN/GdN bilayer. The vanishingly small magnetic moment in SmN prevents its exploration by PNR, so we turn now to the stronger orbital-dominated NdN material for the proposed measurements. PNR permits to investigate the spin spiral in this unique combination of spin-dominated GdN and orbital-dominated NdN, probing the magnetic depth profile in both layers.

Spiral spin structures in GdN/NdN bilayers

Final report on experiment 5-54-179, D17

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The objective of the experiment was to investigate interlayer exchange in GdN/NdN bilayers by polarised neutron reflectometry (PNR). Previous SQUID and XMCD measurements provided indirect evidence for the existence of a spiral spin structure in GdN/NdN bilayers. The spiral structure arises from the competition between the ferromagnetic Gd-Nd exchange across the interface and the Zeeman interaction in the orbital-dominated ferromagnet NdN. PNR is the ideal method to provide direct evidence for the spiral spin structures developing in both layers as a function of the applied magnetic field. In the course of the experiments it became clear that the samples had changed on the journey from Wellington to ILL, despite our established practice of sealing them in a vacuum desiccator. The samples had not changed visibly, but most likely they were oxidised, which could explain the low density and high roughness found in the analysis of the PNR data by Thomas Saerbeck, shown below. The results are thus not representative of pure GdN/NdN layers and no conclusions about the development of spiral spin structures in this system could be drawn.

GaN/NdN/Al_2O_3(substrate)

The single NdN layer was measured to independently establish the NdN magnetic moment and as a reference for the GdN/NdN bilayer. PNR without polarisation analysis was performed at 5 K, well below T_C, and at 100 K, well above the T_C of NdN. Therefore, only at 5 K a magnetic splitting of the R+ and R- reflectivities is expected. The recorded reflectivity was fitted to a slab model describing the layers, the substrate and their interfaces. Interfaces between two materials are simulated with a Gaussian density profile whose standard deviation can be associated with the roughness of the layer. The scattering length density (SLD) profile resulting from the fits is shown in Figure 1. The data and corresponding fits are shown in Figures 2 and 3. The fits are of good quality and follow all the features of the data.

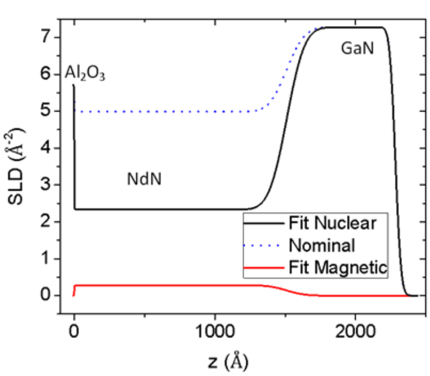

Figure 1: SLD profiles (black and red) obtained from fits to the data at 100 K, 1 T and 5 K, 4 T. The red profile represents the magnetic contribution to the scattering length. The blue dotted line shows the nominal SLD using literature values for the NdN layer.

In the data, the contrast in SLD between two layers and the instrumental resolution determine the height of the oscillations. The resolution is well known, therefore only roughness and density differences remain as fitting parameters. An even higher layer roughness further reduces the contrast, which is the opposite of what is needed to explain the well pronounced fringes in the data. In order to fit the data, the SLD of the NdN layer had to be reduced by more than a factor of 2. The parameters are listed in Table 1. The fitted density N amounts to 0.468 the nominal density of 0.02925 formula units/$Å^3$. The fit was performed without altering the chemical composition of the NdN layer. A more likely scenario is that oxygen was introduced into the lattice and both density and composition change, but the data is insufficient to draw quantitative conclusions. Alternative fitting approaches, namely changing the densities of the substrate or capping layer or Ga-rich intermediate layers did not give better results. Moreover, XRR data recorded by Vera Lazenka from KU Leuven after the PNR measurements could be fitted with the low density model of the neutron data (Figure 4). Since the aim was to study pure NdN and there is no reliable information about the chemical composition of our sample, further interpretation of the data will not be useful.

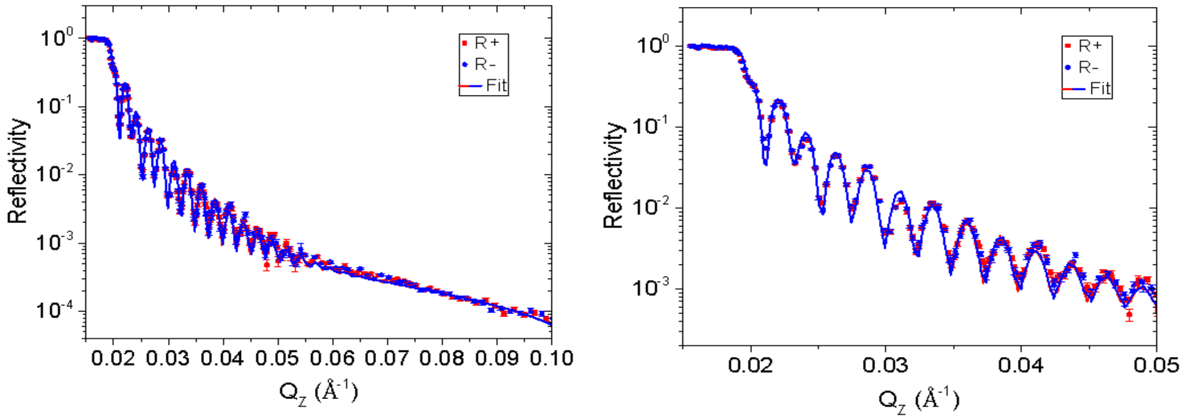

Figure 2: PNR data and fit of GaN/NdN/Al_2O_3 at 100 K in 1 T. The right panel shows only the low Q_Z region. No magnetic moment is included in the fits.

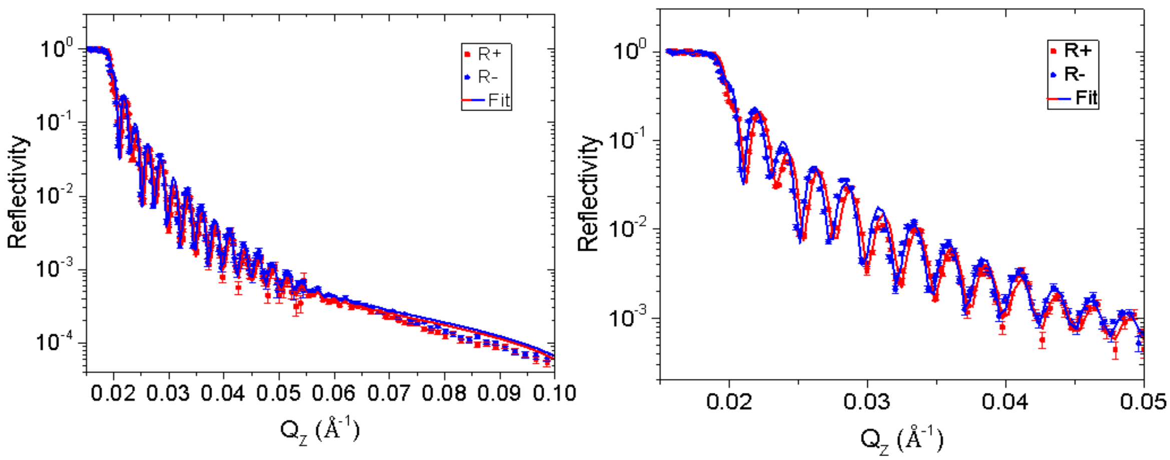

Figure 3: PNR data and fit of GaN/NdN/Al_2O_3 at 5 K in 4 T. The right panel shows only the low Q_Z region. The structural model is the same as at 100 K, but a magnetic moment of 0.77 μ_B/unit cell is included.

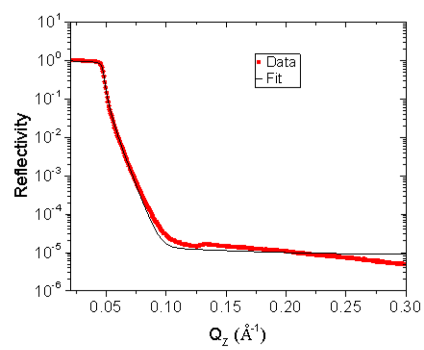

Figure 4: XRR of GaN/NdN/Al_2O_3 and fit.

Table 1: Fit parameters of the model stack.

Material	Thickness (Å)	Roughness (Å)	Fitted N (formula units/Å^3)	b (10^{-5} Å)	M (μ_B/unit cell)
GaN	772	27	0.0437	16.65	0
NdN	1510	100	0.0137	17.05	0.77
Al_2O_3	-	12.6	0.0235	24.31	0

GaN/NdN/GdN/AlN/Al_2O_3(substrate)

PNR without polarisation analysis has been performed at 5 K, with several applied fields. At an external field of 4T, magnetic saturation is expected, leading to a full magnetic moment to be observed in the PNR. At lower external fields, the magnetism is expected to break into domains, leading to a reduction of the observed magnetic moment. The nominal SLD profile for the nominal layer thicknesses GaN(80nm)/NdN(4.5nm)/GdN(65nm)/AlN(substrate) in the left panel of Figure 5 is obtained assuming a magnetisation of 4μ_B/GdN and 1μ_B/NdN. The large thickness of the AlN buffer layer is not resolved in the PNR experiment and therefore it is assumed as a substrate.

Starting from this profile, several models with different roughnesses of each interface and magnetisation distributions were tested. The best fit is shown in the left panel of Figure 6 along with the data. The corresponding SLD profile is shown in the right panel of Figure 5. Also, we tried to vary the nuclear SLD to account for possible oxidation. No model with a moderate roughness was found that has the approximate expected SLD of the materials and still fits the data. Fitting of the PNR profile made clear that the roughness, especially of the GdN layer is too high to draw conclusions about the much thinner NdN layer. The SLD of individual layers also had to be adjusted to achieve a reasonable fit to the data. Since both roughness and SLD needed to be adjusted, the model is not unique. XRR measurements (not shown) confirmed a high roughness and density mismatch.

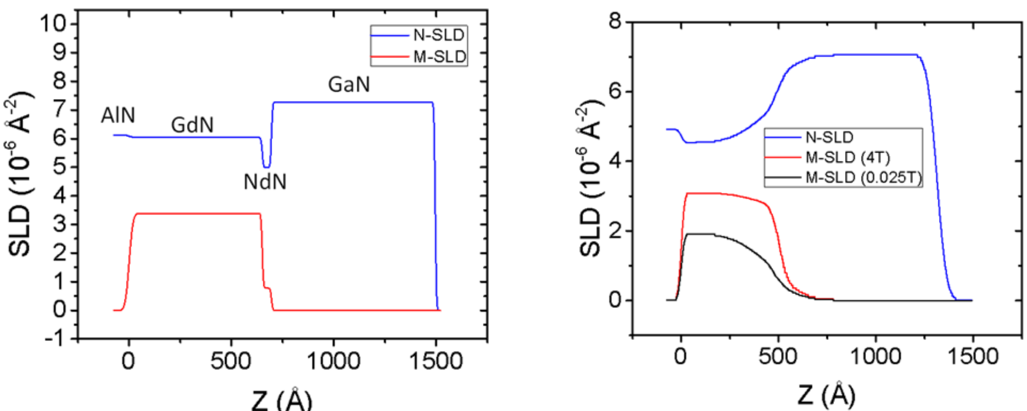

Figure 5: Left panel: Nominal SLD profiles at saturation with $4\mu_B$/GdN and $1\mu_B$/NdN. The magnetic SLD is only shown for the saturated case. Right panel: SLD profiles corresponding to the fits shown in Figure 6.

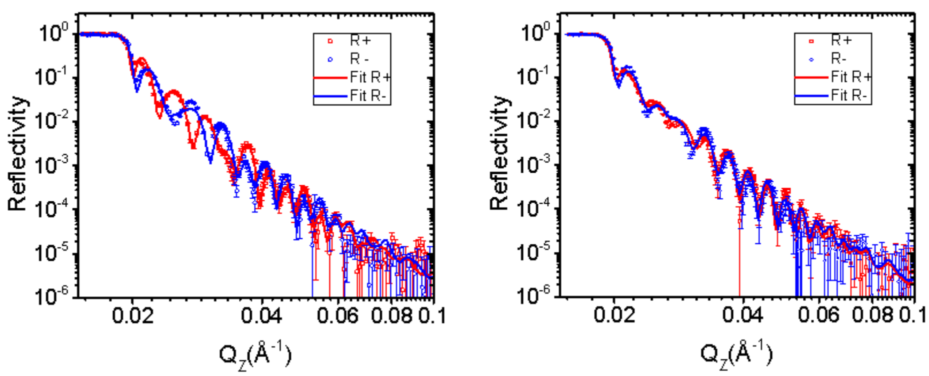

Figure 6: PNR data and fit of the GdN/NdN sample in two spin channels in 4T (left panel) and 0.025 T (right panel) external fields.

The right panel of Figure 6 shows the measurement and fits at a lower external field of 0.025T, which is below the coercivity and therefore a magnetic domain formation is expected. The fits assume the same nuclear structural model as in the high field case. A fit to the data is achieved by only adjusting the magnetisations of NdN and GdN, which indicates that the nuclear model is satisfactorily describing the underlying structure.

Table 2: Fit parameters of the model stack at 4T. %SLD shows the adjustment of the nuclear SLD as a factor.

Material	Thickness (Å)	Roughness (Å)	Nominal SLD (10^{-6}Å^{-2})	Nominal Mag. SLD (10^{-6}Å^{-2})	% SLD	M (4T) (μ_B/unit cell)	M (0.025T) (μ_B/unit cell)
GaN	811	39	7.28	0	0.97	0	0
NdN	75	30	4.99	0.77	1.0	3.27	0.538
GdN	425	137	6.04	3.39	0.75	3.655	2.27
AlN	-	15	6.13	0	0.8	0	0

Table 2 summarizes the fit parameters of the above model. As in the case for the single NdN layer, the change in SLD and overly high roughness may be originating from oxidation of the sample. In conclusion, no meaningful data about the development of a spiral spin structure can be drawn from the obtained data due to a deterioration of sample quality before the experiments.