Experimental report

14/08/2022

Proposal: **5-54-379**

Council: 4/2021

Title: Magnetic correlations in room-temperature skyrmion multilayers

Research area: Physics

This proposal is a new proposal

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Experimental team: Victor UKLEEV

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Samples: Ta|Pt|(CoFeB|Ru|Pt)|Pt

Instrument	Requested days	Allocated days	From	To
SUPERADAM He3 Spin Filter	7	4	20/09/2021	24/09/2021

Abstract:

Magnetic multilayers composed of alternating ferromagnetic / heavy-metal layers are one of the most technologically promising classes of skyrmion-hosting systems due to number of their advantages, such as skyrmion stability at room temperature and their tunability via layer engineering. Through the combination of broken inversion symmetry and spin-orbit-coupling at the interfaces, Dzyaloshinskii-Moriya interaction is induced that leads to stabilization of Néel-type skyrmions in finite magnetic fields. Here we propose to utilise the polarized neutron reflectometry method that is optimized for probing multilayered films and provides important layer-resolved information on magnetic structure of the MMLs. By using the parameters deduced from PNR modelling we will be able to refine the Hamiltonian parameters used for micromagnetic models. This information will allow the further improvement of both material and technological aspects of the samples, thus making further steps towards the real-life applications of room-temperature skyrmions or other non-collinear topological 3D textures in MMLs.

5-54-379 Experimental report

Magnetic correlations in the room-temperature skyrmion multilayers

Magnetic multilayers (MMLs) composed of alternating ferromagnetic / heavy-metal layers are one of the most technologically promising classes of skyrmion-hosting systems due to number of their advantages, such as skyrmion stability at room temperature and their tunability via layer engineering. Through the combination of broken inversion symmetry and spin-orbit-coupling at the asymmetric interfaces, Dzyaloshinskii-Moriya interaction (DMI) is induced that leads to stabilization of Néel-type skyrmions in finite magnetic fields. In this experiment utilized the polarized neutron reflectometry (PNR) method that is optimized for probing multilayered films to provide important layer-resolved information on magnetic structure of the MMLs. By using the parameters deduced from PNR modelling we were be able to refine the Hamiltonian parameters used for micromagnetic models.

The experiment has been performed at the polarized monochromatic instrument SuperADAM with polarization analysis in the specular mode and without analysis in the off-specular mode, due to the limited angular acceptance range of the analyser. Unfortunately, the ^{3}He cell requested for this experiment was not provided by the ^{3}He team due to the technical problems.

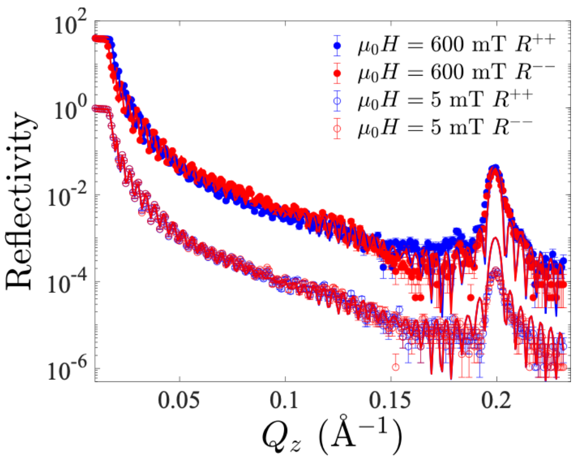

Figure 1. PNR curves of the non-spin-flipped signals measured in the remanence (5 mT) and saturation (600 mT) magnetic fields

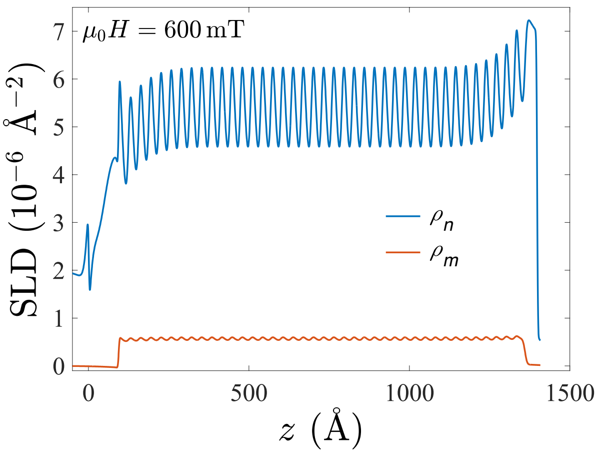

Figure 2. Nuclear and magnetic SLD profiles of the multilayer extracted from the PNR by the fitting routine.

The standard 0.8 T vertical field electromagnet and rotatable sample holder for room-temperature experiments were employed. Neutrons with wavelengths λ = 5.21 Å were used. Polarization of the direct beam was measured by analyzer prior to the experiment. Flipping ratio of 250 was found at applied magnetic field of 10 mT.

The specular PNR was carried out with polarization analysis using the supermirror analyser, i.e. all 4 spin components R^{++}, R^{-+} , R^{+-}, R^{--} of reflectivity were detected. The off-specular PNR experiment was performed without an analyzer, i.e. only summed R^{+} and R^{-} components of spin-flipped and non-spin-flipped intensity were acquired. Reflectivity was detected by the standard two-dimensional position-sensitive detector. PNR experiment has been performed for layer-resolved measurement of magnetization distribution inside the |Ta 5|Pt 7|(Pt 1.0|$Co_{40}Fe_{40}B_{20}$ 0.8|Ru 1.4)$_{x40}$|Pt3 multilayer grown on a 3-mm thick Si substrate.

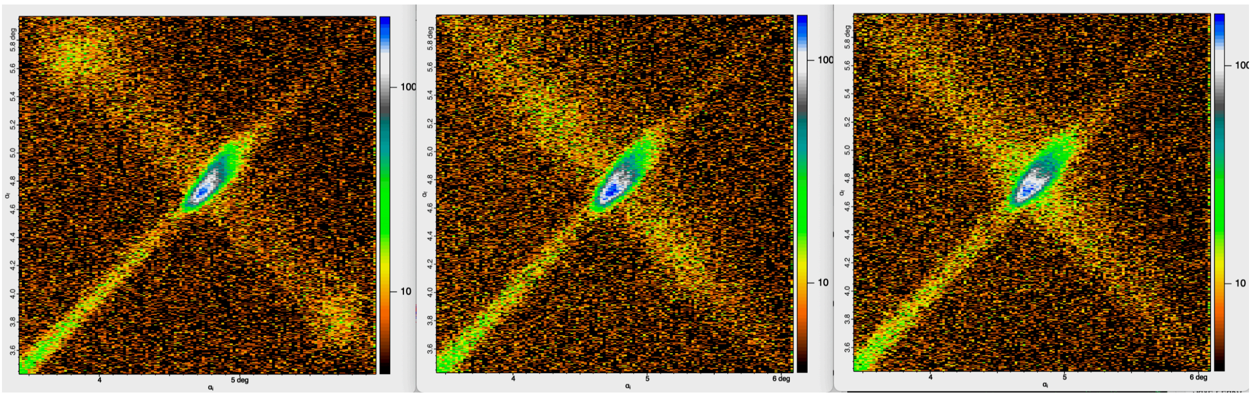

Figure 3. Off-specular PNR maps measured in the remanent state after the field training and consequent azimuthal rotation of the sample by a) 0 deg; b) 60 deg and (c) 90 deg.

The measured specular PNR curves were fitted using GenX software (Fig. 1) which allowed to extract thickness, roughness, nuclear and magnetic scattering length density (SLD) profiles of the MML. The reconstructed nuclear and magnetic SLDs in the saturated state (in 600 mT) are shown in Fig. 2. Overall, the structural and magnetic parameters correspond very well to the values expected from laboratory measurements. No magnetic moments induced in Pt and Ru layers by proximity to ferromagnetic $Co_{40}Fe_{40}B_{20}$ were detected in the present model.

The off-specular PNR was measured without an analyser at a guide magnetic field after the field-training procedure. The sample was degaussed by the vertical field cycling from +-0.7 T to 0 with the field-decreasing steps. This procedure results in aligning of cycloidal domains with the wavevector **q** perpendicular to the field. Then, the PNR maps were measured with the sample oriented with a few azimuthal angles respectively to the field training axis, as shown in Figure 3. Firstly, two well-defined Bragg peaks corresponding to the highly-oriented cycloidal modulation perpendicular to the training field and having the period of 250 nm is seen in the left panel. Upon azimuthal rotation of the sample (middle and right panels in Fig. 3) the peaks merge due to the increasing size of the cycloidal domain projection in plane of the off-specular scattering (i.e. the cycloidal wavevector merges gets parallel to the incident vector of neutrons $\mathbf{k}_i$). Finally, when the $\mathbf{q} \parallel \mathbf{k}_i$ only a diffuse tail of the off-specular PNR remains and the Bragg peaks merge with the specular beam.

The observation of the cycloidal stipe domains as a Bragg spots by the off-specular in the present work is unique and is first to our knowledge. Indeed, in our recent SANS experiment at D33 from analogous system (exactly the same, except the substrate thickness), we had to tack over a 30 20x20 mm^2 samples to achieve the similar signal-to-noise ratio as in the present PNR experiment. Indeed, the grazing-incidence geometry of the experiment is much more efficient than the forward SANS in case of thin films. The mentioned D33 polarized SANS experiment was inconclusive in terms of determination of the Neel-to-Bloch domain fractions in the MMLs due to the low flipping ratio (of 20) available. SuperADAM allows to perform the same experiment with ^3He cell in the off-specular geometry with the flipping ratio of 600.

In summary, we conclude that the off-specular PNR is extremely effective for studying skyrmionic MMLs. Further experiments with ^3He cell for polarisation analysis are highly demanded to clarify the ration between Neel (DMI-induced) and Bloch (dipolar-induced) domain walls, that seem to be inaccessible by any other experimental technique.