Experimental report

17/02/2020

Proposal: **5-54-305** **Council:** 4/2019

Title: Determining the magnetic modulation and phase diagram of skyrmion-hosting magnetic multilayers by SANS

Research area: Physics

This proposal is a new proposal

Main proposer: **Jonathan WHITE**

Experimental team: Victor UKLEEV
Jonathan WHITE
Nicolas REYREN
Fernando AJEJAS BAZAN

Local contacts: Robert CUBITT
Charles DEWHURST

Samples: |Ta10|Pt8|(CoFeB|Ru1.2|Pt0.6)xN|Pt2, N=20,40

Instrument	Requested days	Allocated days	From	To
D33	6	4	10/02/2020	14/02/2020

Abstract:

In magnetic skyrmion research, SANS is a well-known and pivotal probe of skyrmions in bulk chiral magnets like MnSi. Surprisingly, SANS is scarcely applied to study spirals and skyrmions in the huge class of synthetic host systems, most importantly in magnetic multilayers (MML) with repetitions of ferromagnet (FM) and heavy-metal layers. Here we propose a D33 unpolarized (4 days) and polarized (2 days) SANS study of the MMLs |Ta10|Pt8|(CoFeB0.8|Ru1.2|Pt0.6)xN|Pt2, with N=20,40 the repetition number, and other numbers denote thickness in nm. Using PolSANS our goal is to determine an average rotation sense of the spiral and skyrmion modulations across the entire MML, this being a first for this class of system. These data will complement recent X-ray magnetic scattering (XRMS) experiments that probe only the top few layers of the MML. Using unpolarised SANS the goal is to provide a first exploration of the microscopic magnetic field versus temperature (T) phase diagram below room T. The anticipated results will allow parameterization of critical interactions such as the DMI over an entire MML, and not just the top few layers of the MML that have been studied up to now.

Determining the microscopic magnetism of skyrmion hosting magnetic multilayers by SANS

J.S. White [1], V. Ukleev [1], F. Ajejas [2], N. Reyren [2], V. Cros [2] and R. Cubitt [3]
[1] Laboratory for Neutron Scattering and Imaging, Paul Scherrer Insitut, CH-5232 Villigen PSI, Switzerland
[2] Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, Palaiseau, France
[3] Institut Laue-Langevin (ILL), 71 avenue des Martyrs, CS 20156, 38042 Grenoble cedex 9, France

SANS was applied to study the microscopic magnetism of skyrmion-hosting magnetic multilayers (MMLs). Two MML systems were studied, with either 10 or 40 repetitions of the magnetic trilayer. In each MML type, we successfully observed magnetic scattering peaks due to stripe domains at zero field and room temperature. Higher-order peaks were also observed in each MML, and found to display a peculiar field-dependence at room temperature which can be confronted with the expectations of micromagnetic simulations. Further measurements done below room temperature provide the overview of the low temperature phase diagram for the first time.

Topological magnetic skyrmions are of intense interest from a technological perspective due to their nanometric size and propagation under low current density. The two largest classes of skyrmion host system are bulk non-centrosymmetric magnets [1] and synthetic magnetic multilayers (MMLs) [2]. In each system the Dzyaloshinskii-Moriya interaction (DMI) is key for skyrmion formation, with skyrmions nucleated out of a spiral-ordered phase by an out-of-plane magnetic field. SANS is an established probe of the spiral magnetism and skyrmions in bulk crystals, but scarcely applied for studying MMLs. However, since the magnetic structures in MMLs are studied mainly by probes sensitive to just the top layers (e.g. MFM, resonant soft x-ray scattering), and usually just at room temperature (T), there is scope for SANS to provide important volume-averaged information on the microscopic magnetism over a broader parameter space. Here we applied unpolarized SANS at D33 to study two MML samples of different thicknesses.

Two MML systems synthesized by sputtering on SiO_2 wafers were studied, namely Ta5|Pt8|(CoFeB0.8|Ru1.4|Pt1.0)xN|Pt2 with N =10,40. In this recipe, the numbers correspond to the layer thicknesses in nm, while N denotes the number of repetitions of the magnetically relevant (CoFeB|Ru|Pt) trilayer. So, for each MML of N=10 (40) repetitions, the total thickness of magnetic CoFeB that gives rise to the SANS signal is 8 nm (32 nm). To generate sufficient signal for successful SANS studies, we studied 25 MML stacks for each N, so that the total scattering volume for N=10 (40) was 200 nm (800 nm). We studied samples with different N, since this parameter controls the relative strength between the DMI and dipolar energies [2] implying different magnetic structures and properties in the two MMLs.

At D33 the MML stacks were loaded into the ORTF SANS cryomagnet. We used SANS to study the out-of-plane magnetic field evolution of the microscopic magnetism in the MMLs. At each T, the zero-field state in the MML stack was prepared by an in-plane degaussing procedure. This resulted in a well-ordered arrangement of spiral domains generating magnetic SANS peaks with propagation vectors aligned perpendicular to the degaussing field. In addition to these first-order peaks, higher-order peaks up to third-order were also observed indicating anharmonicity of the spirals. Fig. 1 shows such data obtained at T=300 K and zero field for the N=40 MML. On sweeping the out-of-plane magnetic field,

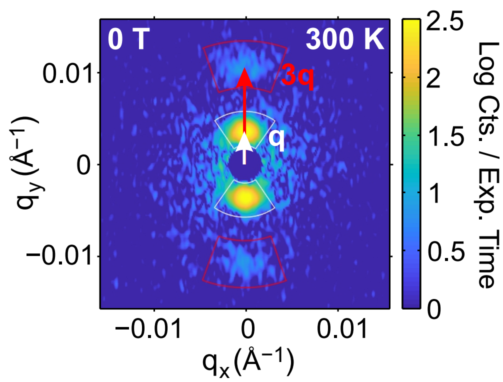

Figure 1: D33 SANS pattern from the N=40 MML at zero-field and 300 K. The neutron beam is parallel to the out-of-plane film axis. In this case the 2**q** peak is not observed.

we observed an unusual non-monotonic field-dependence of the second- and third-order peaks. Such data are valuable, since the ratios of different order peak intensities can be compared with the results of micromagnetic simulations, and allow the refinement of effective model parameters.

The observation of skyrmions proved to be more challenging. In MMLs, they rarely form a lattice arrangement, and instead they are more sparsely dispersed. Nonetheless, in the N=10 MML stack at room T, we observed the SANS intensity to rearrange under increasing magnetic field, with the stripe-domain peaks transforming into a homogeneous ring of intensity. The intensity ring we observe is consistent with the existence of a sparse array of skyrmions with no orientational order but a finite radial correlation length. This outcome is consistent with our MFM observations. In both MML stacks, we performed similar field-sweeping measurements at cryogenic Ts to learn the extent of the skyrmion nucleation in the phase diagram. Again these data will be confronted with the results of ongoing micromagnetic simulations. Further SANS measurements using both unpolarized and polarized neutrons are planned to further this first successful study towards publication.

[1] N. Nagaosa and Y. Tokura, Nat. Nanotech. **8**, 899 (2013)

[2] A. Fert, N. Reyren and V. Cros, Nature Review Materials **2**, 17031 (2017)

Proposal-number: 5-54-305
Instruments: D33