# Experimental report

27/07/2023

**Proposal:** **5-51-595** **Council:** 10/2022

**Title:** Origin and temperature dependence of DMI in high-PMA FePd studied by ¿-GISANS

**Research area:** Physics

**This proposal is a new proposal**


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**Samples:** high-PMA FePd/Pd
high-PMA FePd/spacer/Pd

| Instrument | Requested days | Allocated days | From | To |
|---|---|---|---|---|
| SUPERADAM He3 Spin Filter | 5 | 5 | 04/06/2023 | 09/06/2023 |


**Abstract:**

Néel-type magnetic chiralities in thin FM/HM multilayer systems are shown to be controlled by the spin-orbit coupling parameter and have been proposed for applications in spintronic devices. However, Bloch-type chiral preferences have rarely been observed, but seem to play an important role in thicker multilayer systems. We propose an in-depth study of Bloch-type magnetic chiral domain walls in the FM/HM multilayer system FePd/Pd, using pi-GISANS with polarization analysis, (i) in dependence of the polarization direction of the neutron beam, and (ii) in dependence of temperature which impacts on the domain wall width.

Experimental Report
Instrument: SuperAdam
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**Title: Origin and temperature dependence of DMI in high-PMA FePd studied by π-GISANS**
**Experiment Date: 04/06/2023 – 09/06/2023**
**Experimental Team: Annika Stellhorn, Alex Backs, Wai-Tung Lee**

(i) Introduction

Néel-type magnetic chiralities in thin ferromagnetic / heavy metal (FM/HM) multilayer systems were shown to be controlled by the spin-orbit coupling parameter and have been proposed for applications in spintronic devices. However, Bloch-type chiral preferences have rarely been observed, but seem to play an important role in thicker multilayer systems. We have studied the Néel- and Bloch-wall contributions, including chiral preferences, in the FM/HM multilayer system FePd/Pd, using polarized pi-GISANS.

(ii) Goals and measurement plans

This experiment aimed at investigating the detailed magnetic domain structure in FePd/Pd in two regards: (a) to map out the magnetization components of out-of-plane oriented magnetic domains, and in-plane oriented domain walls of Néel-type and Bloch-type. For this, in-plane and out-of-plane neutron polarization directions were used to control their magnetic contributions to the non-spin-flip (NSF) and spin-flip (SF) channels. And (b) to investigate the net-chirality in Bloch-type and Néel-type domain walls by measuring the asymmetry of GISANS peaks between the two spin-flip channels (UD and DU).

For a better understanding of the Bloch-type and Néel-type contributions, FePd/Pd thin films with different perpendicular magnetocrystalline anisotropy (PMA) were prepared: (i) with low PMA ($FePd_{low}$), expected to contain mainly Néel-type domain walls (also called "closure domains"), and (ii) with intermediate PMA ($FePd_{mid}$), expected to contain Néel- and Bloch-walls [1,2].

As sketched in Figure 1, Bloch-type walls are screw-type domain walls between the out-of-plane domains, typically appearing in thick films, while Néel-type walls can be understood as surface closure domains, dominating in thinner magnetic films, and are of cycloidal nature. We have investigated the x,y,z-polarization dependence and analyzed the UD-DU GISANS peak asymmetry for the y-polarization direction in $FePd_{mid}$ and Nb/$FePd_{mid}$ (with a Nb cap).

(iii) Sample Details and Instrumental Configurations

During the beam time, three samples were studied: (i) $FePd_{low}$ with low-PMA, (ii) $FePd_{mid}$ with intermediate PMA, and Nb/$FePd_{mid}$ with intermediate-PMA and a Nb capping-layer. The in-plane domain structure in all samples was aligned along the neutron beam direction, with domain periods corresponding to GISANS peaks at $\boldsymbol{Q_y}$ = 0.005-0.007Å$^{-1}$.

The volume-fraction of Bloch- and Néel-type magnetic domain walls are expected to depend on the PMA, with lower PMA favoring larger Néel-type (closure) domains. Figure 1 shows MFM measurements of the in-plane magnetic domain structure for low and intermediate PMA, along with theoretical depth-profiles and the type of magnetic chirality that might result from the domain walls.

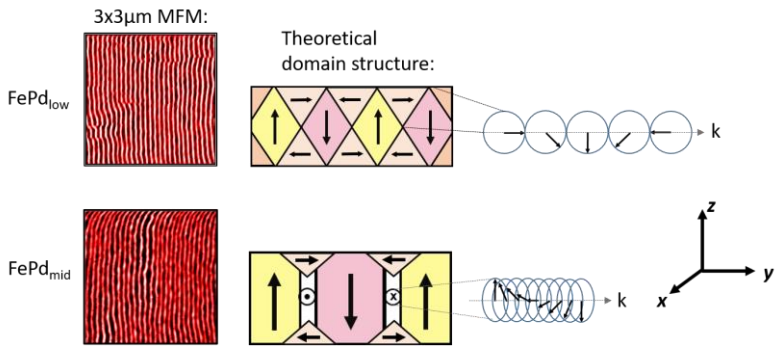



**Figure 1**: (Left) 3x3µm Magnetic Force Microscopy measurements on the in-plane domain pattern of $FePd_{low}$ (top) and $FePd_{mid}$ (bottom) at room temperature. (Right) sketch of the side-view of the magnetic domains in out-of-plane direction (yellow, red), Néel domain walls (closure domains, beige) with cycloidal propagation along $\vec{y}$, and Bloch domain walls (white) with chiral propagation along $\vec{y}$.

Both types of samples pose the advantage of a well-ordered in-plane domain pattern as seen in the MFM images. To map out the contributions of Néel to Bloch-type walls (plan (a)) for each sample, we have investigated pi-GISANS in three different polarization directions: $\vec{P}||\vec{x}$, $\vec{y}$, and $\vec{z}$-directions, as marked in Figure 1, and guide field strength of 0.5mT in each direction. This leads to scattering contributions from the out-of-plane domains and the Néel-/Bloch-type walls in different spin-channels depending on the polarization direction. Due to the cycloidal propagation of Néel-walls [3] in $FePd_{low}$, a net chirality with $(\vec{m_1} \times \vec{m_2})| |\vec{x}$ can only be observed with a neutron polarization $\vec{P}||\vec{x}$ [4], whereas a net chirality of Bloch domain walls in $FePd_{mid}$ would be observable using $\vec{P}||\vec{y}$ (plan (b)). We have used a flexible coil setup to set the orientation of $\vec{B}$ and $\vec{P}$ at the sample position and measured the Flipping ratios for each case (FR($\vec{B}||\vec{x}$) = 150, FR($\vec{B}||\vec{y},\vec{z}$) > 200). A FeSi

supermirror analyser has been used to probe the outgoing neutron polarization. To analyze the necessary $Q_y$-range from -0.001Å$^{-1}$ to 0.001Å$^{-1}$, we have measured all 4 spin channels in different angular positions of the analyzer with respect to the incident beam direction: $\omega_{an}$ = [-0.4, -0.2, 0, 0.2, 0.4]° for measurements in part (a), and $\omega_{an}$ = [-0.2, 0, 0.2]° for measurements in part (b). The specular peak at $Q_y$ = 0 Å$^{-1}$ is superimposed by the direct beam due to the missing $Q_z$-resolution and wide slit-opening in $\vec{z}$-direction, and additionally has been blocked by a beamstop. Each measurement has been normalized with respect to the Monitor.

(iv) Preliminary results of plan (a)

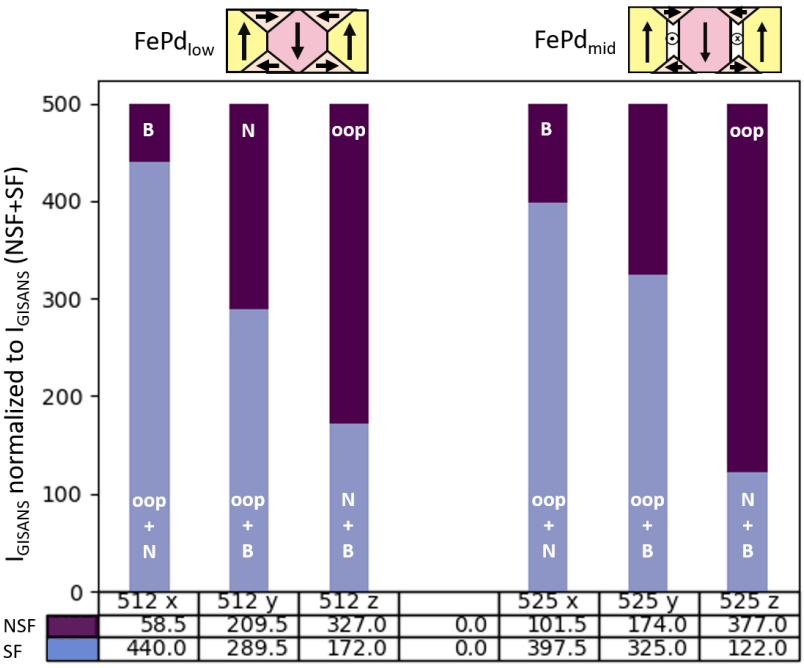
Figure 2 shows the measurements on $FePd_{low}$ as an example. An analysis of the GISANS peak intensities $I_{GISANS}$ of averaged NSF channels ((UU+DD)/2) and averaged SF channels ((UD+DU)/2) for each field direction shows a clear dependence of the peak intensity on the applied field orientation: the NSF GISANS peak intensity is increasing from the $\vec{x}$ to the $\vec{y}$ to the $\vec{z}$ direction, whereas the SF GISANS peak intensity is decreasing. This result is also sketched in the histogram in Figure 3, together with the results of the second sample ($FePd_{mid}$). Together, the results on both samples show a stronger contribution from Néel-type walls in $FePd_{low}$, and from Bloch-type walls in $FePd_{mid}$, which is in accordance with the expected domain wall arrangement shown in Figure 1. It has to be noted, that we cannot yet explain why the intensity-sum of NSF($\vec{x}$)+NSF($\vec{y}$) = Bloch + Néel contributions unequal the intensity if SF($\vec{z}$). This could be due to a misalignment of the polarization direction due to the rotation of the neutron spin before and after the sample position. If for example for $\vec{P}||\vec{y}$ the polarization did not completely rotate into $\vec{y}$, but keeps components in $\vec{z}$, then contributions from out-of-plane and Néel domain walls get intermixed between the NSF and SF channels, which could explain a too high contribution of the NSF signal in $\vec{y}$. However, this should be equal for both samples, $FePd_{low}$ and $FePd_{mid}$, allowing a qualitative comparison between both samples.

(v) Preliminary results of plan (b)

The measurements on Nb/$FePd_{mid}$ and $\vec{P}||\vec{y}$, show indications for a GISANS peak asymmetry. But despite the longer counting time, the uncertainty is too high to draw clear results on a measured asymmetry. This measurement is planned to be repeated within the next cycle for which we already have granted beamtime (Proposal-ID 5-54-407).

(vi) Summary

In comparison to conventional GISANS, pi-GISANS sacrifices the depth resolution ($Q_z$) in favor of higher flux. Despite this limitation, we have successfully applied the technique to samples with varying contributions of Bloch- to Néel-type magnetic domain walls and have observed clear evidence of the differences of two distinct samples with low and intermediate perpendicular magnetic anisotropy (PMA). In our experiment, we could separate scattering contributions to the GISANS signal from the main perpendicular domains as well as the Néel- and Bloch-type domain walls, by applying different magnetic guide fields and therefore measuring under different orientations of the neutron polarization. Confirming our expectations, we thereby found higher contributions from Néel walls in the low-PMA sample and higher Bloch wall contributions with intermediate PMA.





Literature:
[1] A. Stellhorn, PhD. thesis, RWTH Aachen University (2021).
[2] A. Stellhorn *et al.,* New J. Phys. **22**, 093001 (2020).
[3] W. Schweika, J. Phys. Conf. Ser. **211**, 012026 (2010).
[4] J. Bertinshaw *et al.,* Nat. Comm. **7**, 12664 (2016).


**Figure 3**: Histogram on the contributions of $I_{GISANS}$ for the averaged NSF (UU+DD)/2 and SF (UD+DU)/2 for each polarization direction to the total intensity $I_{GISANS}$ (NSF+SF). The text marks the interpreted contrubutions from out-of-plane domains (oop), Bloch walls (B), and Néel walls (N).

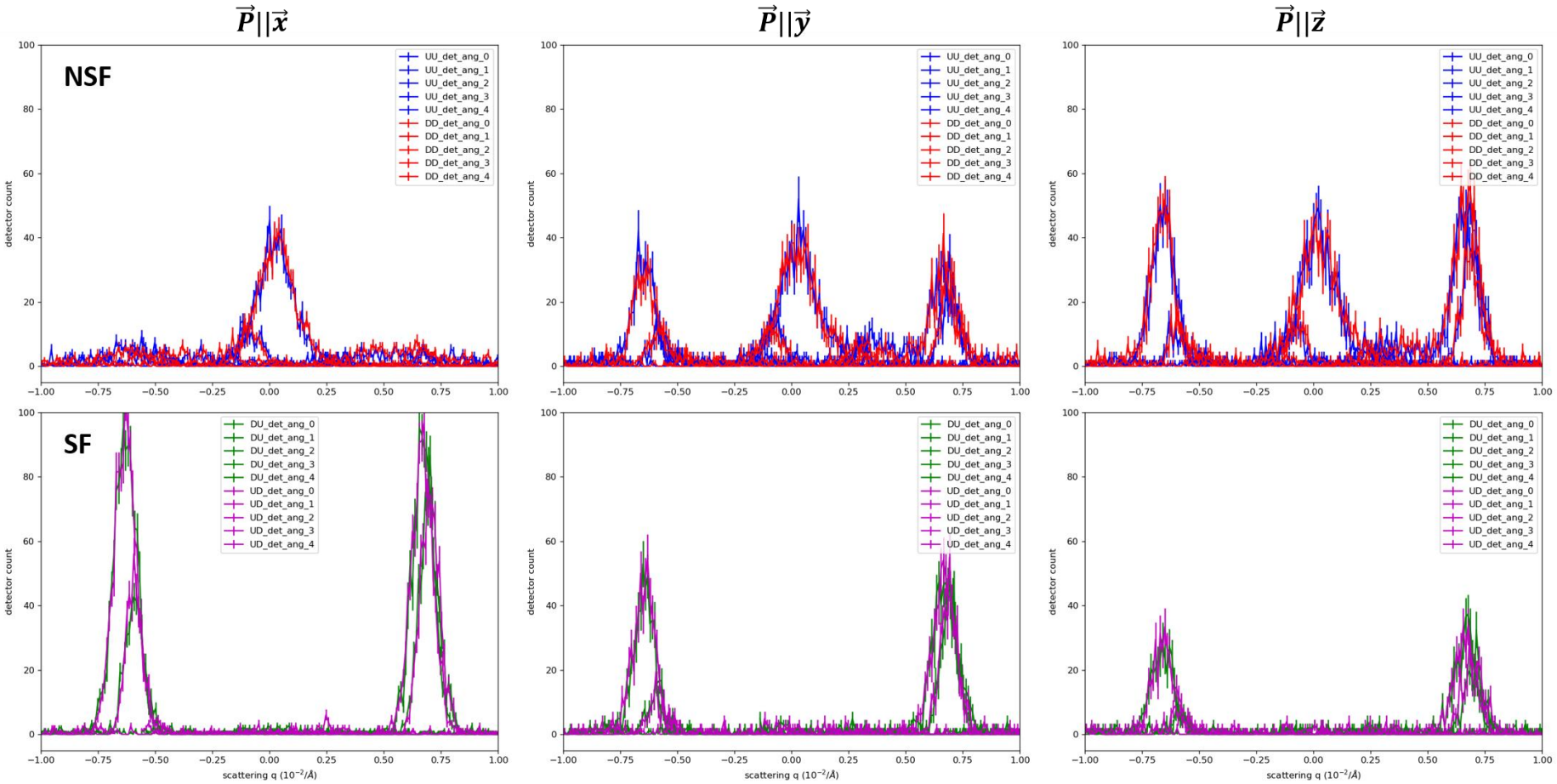



**Figure 2**: Measurement results on FePdlow in all 3 applied field (polarization) directions for the NSF (top) and SF (bottom) channels. Different spin-channels are marked with different colours, wheres same spin-channels in the 5 different analyser orientations are superimposed with the same color code.