

Experimental report

16/08/2023

Proposal: 5-51-594

Council: 10/2022

Title: Anisotropic exchange interactions in FePd thin films probed by GISANS with polarization analysis

Research area: Physics

This proposal is a new proposal

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Samples: Intermediate-PMA FePd/Pd

high-PMA FePd/Pd

low-PMA FePd/Pd

high-PMA FePd/spacer/Pd

Instrument	Requested days	Allocated days	From	To
D33	3	3	29/05/2023	01/06/2023

Abstract:

Magnetic chiralities in FM/HM multilayer systems can be controlled by the spin-orbit-coupling parameter and have been proposed for applications in spintronic devices. In thicker magnetic films, Bloch and Néel wall contributions to the chirality are still the focus of current research. In such systems, interlayer DMI with a non-zero D_z component perpendicular to the sample surface plays a crucial role in generating Bloch wall chiralities. Here, we propose to study these magnetic chiralities in FePd/Pd multilayers as a function of the strength of the magnetocrystalline anisotropy, which changes the contributions of Bloch and Néel wall chiralities. The question about the origin of the interlayer DMI and how to control the competition between chiral Bloch and Néel walls shall be investigated by GISANS with polarization analysis.

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Experimental Team: Annika Stellhorn, Alex Backs, Steffen Tober

(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 [1]. The SOC in such heterostructures can lead to an intralayer Dzialoshinskii-Moriya interaction (DMI) with $\mathbf{D} = (D_x, D_y, 0)$. However, Bloch-type chiral preferences have rarely been observed, but seem to play an important role in thicker multilayer systems. Recently, Pollard *et al.* [2] have shown the stabilization of chiral Bloch walls (BWs) in Co/Pd multilayers by symmetry breaking at the interface and an interlayer DMI with $\mathbf{D} = (0, 0, D_z)$. Carvalho *et al.* [3] have investigated the occurrence of DMI in symmetric Pd/Co/Pd multilayers in dependence of the strength of Perpendicular Magnetic Anisotropy (PMA) due the crystalline structure, and an interdiffusion of Pd and Co leading to an asymmetric defect structure. They found that the interdiffusion as well can cause a non-zero interlayer DMI $\mathbf{D} = (0, 0, D_z)$. Still, questions abound around the origin of this DMI and details about the occurrence of chiral BWs and their competition with NWs remain open.

FePd thin films with high PMA favor the formation of Bloch-type domain walls. In a previous experiment at vSANS, NIST, using polarized GISANS on a Nb/FePd/Pd multilayer, we have found indications for the formation of a net chirality in the BWs of the FePd layer [4]. During our experiment at D33, we aimed at examining this net chirality in FePd by (i) a comparison of Pd/FePd and Nb/FePd, and (ii) an investigation in two different polarization directions with respect to the thin film surface. Following [5], a net-chirality from BWs with $\vec{c} \times (\vec{m}_1 \times \vec{m}_2) \parallel \vec{x}, \vec{y}$ can only be observed for a polarization of the neutrons in \vec{x}, \vec{y} -direction, leading to asymmetric GISANS peaks with intensities $I^- \neq I^+$.

(ii) Sample details and expected results

GISANS with polarization analysis has been performed at room temperature on three samples: (a) 2 samples of a Pd/FePd/Pd structure with high PMA, and (b) one Nb/FePd/Pd structure with high PMA, and in two different directions of the neutron polarization \mathbf{P} with respect to the sample surface: (i) $\vec{P}_{\text{oop}} \parallel \vec{z}$ (out of the surface plane), and (ii) $\vec{P}_{\text{ip}} \parallel \vec{x}, \vec{y}$ (in the surface plane). The coordinate system is defined as sketched in Figure 1, together with the domain structure of both types of samples. Due to the maze-like domain pattern, here we do not differ between the \vec{x}/\vec{y} -directions of \vec{P} , although a non-zero chirality can only be observed if the domain pattern consists of an in-plane preferred orientation [4]. Simulations of the scattering cross-section using the Distorted-Wave-Born-Approximation (DWBA) on a maze-like magnetic domain pattern with preferred in-plane direction are displayed in Figure 2 for \vec{P}_{oop} and \vec{P}_{ip} , respectively. It can be seen that for \vec{P}_{ip} , an asymmetry within the GISANS peaks (and hence a net-chirality of Bloch walls with $\vec{c} \parallel \vec{x}, \vec{y}$) can be observed with much higher intensity, which

is in accordance to the expectations by [5]. The observation of a small asymmetry for \vec{P}_{oop} here is simulated by a deviation of \vec{P} with respect to \vec{z} of 20° .

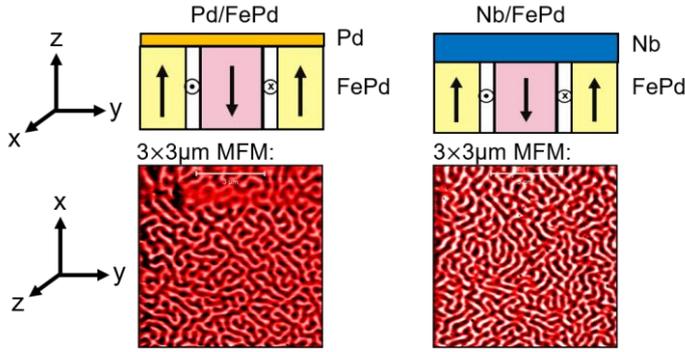


Figure 1: (Top) sketch of the side-view on the magnetic domain structure in high-PMA FePd with two different toplayer: Pd/FePd (left) and Nb/FePd (right). It shows the expected formation of out-of-plane (oop) oriented domains with $\vec{M} \parallel \vec{z}$, and in-plane oriented Bloch walls (BWs). (Bottom) lateral formation of magnetic domains measured by Magnetic Force Microscopy (MFM), showing a maze-like domain pattern.

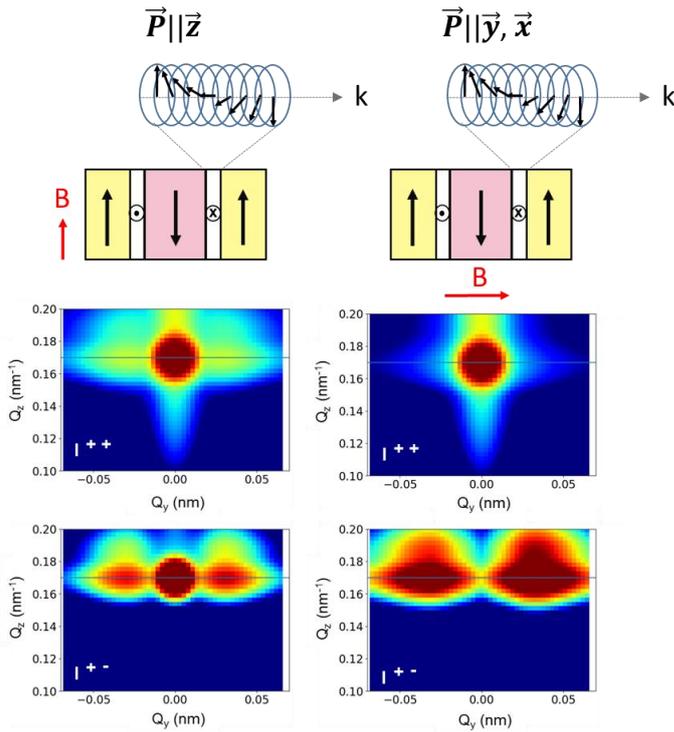


Figure 2: DWBA simulations of the scattering cross section on high PMA FePd with a preferred in-plane domain structure. (Left) for an oop-polarization (with a rotation of \vec{P} with respect to \vec{z} by 20°), and (right) an in-plane Polarization $\vec{P}_{\text{ip}} \parallel \vec{x}, \vec{y}$.

(iii) Instrumental configurations

For the polarization of the neutron beam, a single-polarizing supermirror has been used, and ^3He cells for the analysis, yielding a flipping ratio of $\text{FR} = 38$. The ^3He -cells have been exchanged daily, and direct beam measurements for all four spin channels without sample have been performed throughout the experiments. The magnetic field at the sample has been applied using Helmholtz coils with $B_{\text{sample}} = 10$ G. For the different directions of \vec{P} to the sample surface, the sample has been rotated with respect to the coils field direction. At D33, we only have used the inner detector panel at a sample-to-detector distance of $\text{sdd} = 10.7$ m.

(iv) Preliminary results

All 4 spin channels for the in-plane oriented field with \vec{P}_{ip} and the out-of-plane oriented field with \vec{P}_{oop} , have been corrected for the polarizer, flipper, and analyzer inefficiencies and transmissions. Using python, the values of the spin flipper efficiency (E_{SF}), spin polarizer efficiencies for the spin states parallel and antiparallel to the magnetization direction ($E_{\text{P}+}$, $E_{\text{P}-}$), and the time constant of the ^3He cell have been fit to the direct beam measurements of all 4 spin channels without sample and yield values of $E_{\text{SF}} =$

0.991-0.993, $E_{P+} = 0.959-0.966$, and $E_{P-} = 0.033-0.041$ for the fits to the 3 different He-cells. The efficiency-corrections are slightly overcorrecting the SF measurements of Pd/FePd #2 (\vec{P}_{ip}), and Nb/FePd (\vec{P}_{oop}). A comparison to the uncorrected measurements shows that this does not affect the asymmetry of the GISANS peaks $I^+ \neq I^-$. Figure 4 shows the averaged asymmetry, defined as the averaged ratio of the right and left GISANS peak intensity for the 2 spin-flip channels: $A = I^-(GIS, right) / I^-(GIS, left) + I^+(GIS, left) / I^+(GIS, right)$. Such a definition yields $A = 1$ in case of no difference between I^+ and I^- . A higher deviation from 1 results from a stronger asymmetry. Such an asymmetry is clearly observed for Nb/FePd. Both Pd/FePd samples show less asymmetry, but also weaker scattering intensity in general, probably resulting from a rough sample surface.

(v) Conclusion

In total, the observed spin-flip asymmetries indicate a net-chirality of Bloch domain walls in all high-PMA FePd samples, being a sign for a non-zero intralayer DMI with $\mathbf{D} = (0, 0, D_z)$. The Nb/FePd sample with the strongest asymmetry also has shown the strongest total scattering intensity, which complicates the comparison of asymmetries for samples with and without Nb. In a next step, the origin of this net-chirality has to be examined, e.g. by comparison samples with a non-magnetic spacer, for which unfortunately we did not have time during this experiment.

(vi) Literature

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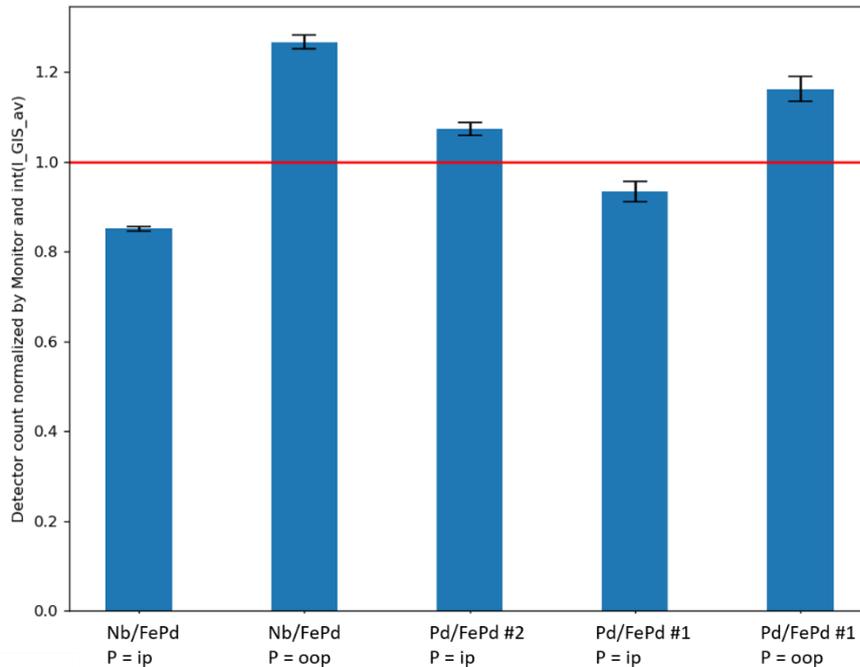


Figure 4: Asymmetry of GISANS peaks for the investigated samples, defined as the averaged ratio of the right and left GISANS peak intensity for the 2 spin-flip channels: $A = I^-(GIS, right) / I^-(GIS, left) + I^+(GIS, left) / I^+(GIS, right)$