Experimental report

05/02/2016

Proposal:	**5-54-197**		**Council:**	4/2015

Title: Specular Reflectivity and Off-specular scattering from artificial magnetic domain patterns

Research area: Physics

This proposal is a new proposal

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Samples: Au(8nm)/CoFe(5nm)/IrMn(10nm)/Cu(50nm)/Si
Au(8nm)/NiFe(5nm)/IrMn(10nm)/Cu(50nm)/Si

Instrument	Requested days	Allocated days	From	To
D17 He3 Spin Filter	3	3	09/12/2015	12/12/2015

Abstract:

The proposed study is a feasibility experiment for the investigation of artificially designed in-plane magnetic domain patterns by polarised neutron reflectometry and off-specular scattering. Stripe shaped domains with in-plane magnetizations are arranged in a head-to-head and tail-to-tail configuration, leading to a charged domain wall equivalent to a magnetization component perpendicular to the surface of the thin film. The magnetic stray field landscape arising from these submicron sized magnetic structures has the potential for positioning and transporting magnetic micro- and nano-objects in liquids and therefore provide an excellent platform for various lab-on-a-chip applications. From this experiment we hope to evaluate in which detail qualitative and quantitative information can be obtained from specular and off-specular neutron scattering. The information obtained will provide the basis for future tailoring and applications of the magnetic templates.

Specular reflectivity and off-specular scattering from artificial magnetic domain patterns
Polarized Neutron Reflectometry Beam Time on D17, December 2015, EXP: 5-54-197

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Motivation:

Magnetic stray field landscapes of micron sized magnetic domains have powerful applications as platforms for positioning and movement of magnetic micro- and nano-objects in liquid environments [1, 2, 3]. The stray fields above the thin film surface are created by charged magnetic domain walls (DW) between artificially designed in-plane domain landscapes [1, 3]. For the tailored design of such devices, a detailed knowledge about the magnetic configuration and emerging stray fields is necessary.

Light-ion bombardment of an exchange bias system can be used to fabricate artificially designed magnetic domain landscapes on different length scales [1, 3]. Stripe patterns of desired width are obtained by He irradiation on an applied magnetic field through a photolithographically grid shaped resist mask. The resulting samples are structurally homogeneous with flat surfaces and only exhibit the in-plane magnetic periodicity with magnetization directions determined by the initial field cooling direction (un-bombarded area) and during irradiation (Figure 1). The choice of the template material defines the intrinsic magnetic properties, such as the magnetocrystalline anisotropy and extension of domain walls between stripes. Here we focus on head-to-head (tail-to-tail) configured domain structures with orientations perpendicular to the stripe grid. The opposing magnetization leads to magnetically charged domain walls, whose stray fields define a magnetic field landscape perpendicular to the surface (Figure 1).

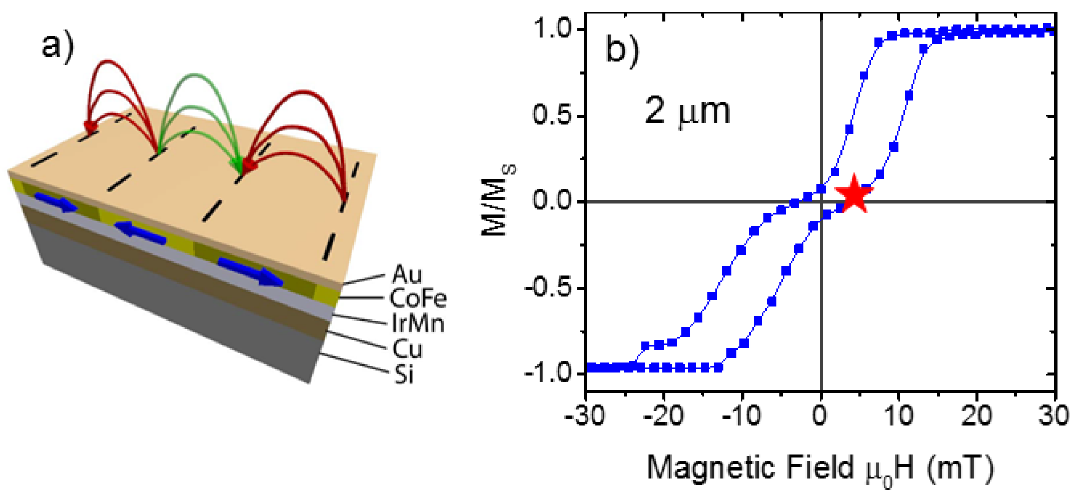

Figure 1: a) Schematic of the magnetic stripe configuration with opposing magnetizations and magnetic stray fields above the sample surface. b) Magnetic hysteresis of the 2μm CoFe stripe pattern used during the experiment.

Using specular polarized neutron reflectometry (PNR) and off-specular scattering (OSS) we aim at the investigation of the lateral magnetic pattern. We hope to gain information on the global magnetic configuration, the intrinsic domain structure and on the domain walls and their extent with respect to the material and stripe width. In addition, the obtained scattering pattern will be used as a reference for future studies looking at guided self-assembly and movement of nano-objects in the stray field landscape.

Experimental details:

The initial experiment was thought as a test time to evaluate the feasibility of the proposed experiment. Over the 3 day experiment we were able to investigate two stripe patterns with 2 μm width, using NiFe and CoFe as magnetic materials. The experimental setup requires the use of the ^{3}He cell, which is very time consuming. In addition, the acquisition times were long (~ 12 h, including periodic polarization efficiency checks) in order to gain sufficient statistics on low probability spin-flip (SF) processes of the domain pattern.

Figure 2 illustrates the measurement geometry. The external magnetic field, and therefore the neutron polarization, was oriented parallel to the long axis of the stripe and perpendicular to the local stripe magnetization. This configuration leads to spin-flip off-specular scattering (SF-OSS). In the case of opposing stripe magnetizations with equal magnitude, no lateral periodicity along the applied field direction is observed and therefore no non spin-flip off-specular scattering (NSF-OSS) is expected. Deviations in magnitude and angle in individual domains of the idealized schematic in Figure 2 lead to a change in the non spin-flip (NSF) and SF scattering magnitudes. A reference measurement was recorded in the saturated state overcoming the local exchange bias and orienting the global magnetization along the stripes.

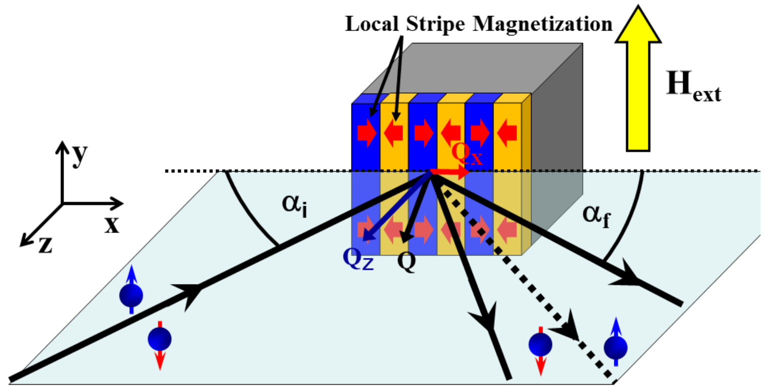

Figure 2: Measurement geometry of the magnetic stripe pattern. The external field is applied along the stripes perpendicular to the local domain magnetization. The scattering plane is oriented perpendicular to the stripes.

Results:

Figure 3 shows the specular reflectivity of the CoFe/IrMn 2μm stripe pattern obtained in saturation at 526 mT external field. A clear splitting between the non-spin flip R^{++} and R^{--} spin channels is observed which provides the overall magnetic moment of the layers. Fitting of the specular reflectivity together with x-ray reflectivity will provide the chemical and magnetic structure in depth, which will be required for the analysis of the off-specular magnetic scattering.

Figure 4 shows off-specular scattering contour plots in all four spin channels obtained from the CoFe/IrMn sample measured in an external field of 4.2 mT after negative saturation. The data is presented in the instrumental coordinates of incident and outgoing angle α_i and α_f, respectively. Therefore, the specular reflectivity runs obliquely in the plot along $\alpha_i = \alpha_f$. All contour plots have the same logarithmic intensity scale. To the lower left corner of each panel a remainder of the direct and refracted beam is observed (marked DB). At $\alpha_i = 1.2°$ a vertical intensity streak is observed which is an instrumental artefact and does not result from the sample. Clear off-specular scattering is observed along curved lines with respect to the specular line. Up to third order Bragg diffraction is observed in both NSF (R^{++} and R^{--}) and SF (R^{+-} and R^{-+}) channels. The locations confirm the intended periodicity of 4 μm. The scattering has not yet been corrected for the polarization efficiency of the incoming and outgoing beam. This correction must be performed very carefully and data reduction is still ongoing. The SF-OSS is substantially stronger than the observed NSF-OSS, which agrees with the proposed magnetic structure in Figure 2.

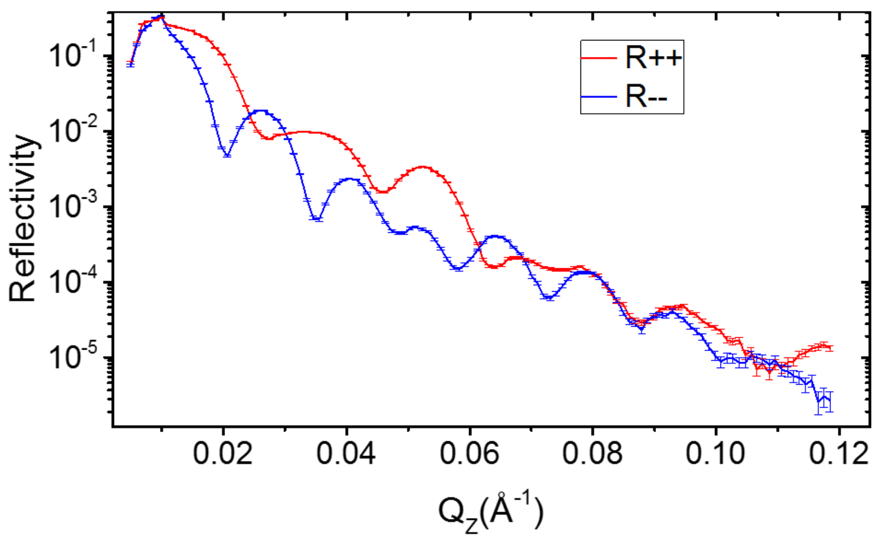

Figure 3: Specular reflectivity of the 2μm CoFe/IrMn stripe pattern in saturation at 526 mT applied along the stripes. The data is not yet corrected for overillumnation.

The small difference in R^{++} and R^{--} specular reflectivity, observed in the intensity oscillations along the specular line indicates that the sample is not in a fully demagnetized state along the external field direction. However, the NSF-OSS observed is comparably weak, especially taking into account the finite polarization of the beam. Interestingly, a strong 2nd-order Bragg diffraction is clearly observed with almost equal intensity in the NSF-OSS and SF-OSS. This indicates a magnetization which breaks the periodic stripe pattern, either due to canted magnetization at the domain walls or more random magnetizations within a stripe.

A similar scattering pattern was obtained from the sample having NiFe as the ferromagnet. Here the overall OSS is weaker due to a smaller magnetic moment of NiFe and therefore less stripe-to-stripe contrast. However, the general features show a very good agreement with expectations from stripe width and general magnetic alignment. Interestingly, the intensity distribution between NSF and SF appears to be different, but a more quantitative analysis is required to draw conclusions.

Summary and conclusions:

In summary, the experiment was successful in that detailed OSS was measured of two stripe domain materials. Important information, like the stripe width and overall magnetic configuration, have already been extracted. The obtained results illustrate the feasibility of the experiments on D17 and the amount of information that can be obtained in reasonable acquisition times (for a similar study we required 24 h on OFFSPEC, ISIS, instead of 10 h on D17). Additional stripe patterns with different width have been fabricated and will be proposed for a future experiment. Data reduction and quantitative analysis of all specular and off-specular data are ongoing.

References:

[1] F. Ahrend *et al.* J. Magn. Magn. Mater. 381 (0), 292 (2015).

[2] A. Ehresmann *et al.* 3D-CONMAG - Concept paper for application of a SFB transregio. (2014)

[3] D. Holzinger, *et al.* J. Appl. Phys. 114 (1), 013908 (2013).

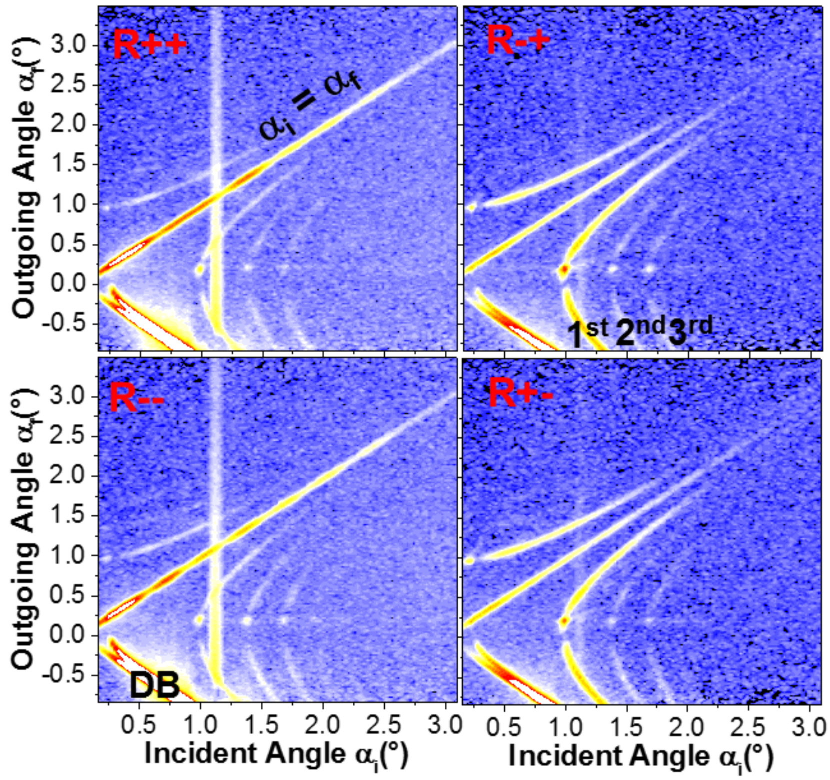

Figure 4: OSS contour plots from 2μm CoFe/IrMn stripe patterns at 4.2mT applied along the stripes and perpendicular to the imprinted domain magnetization.

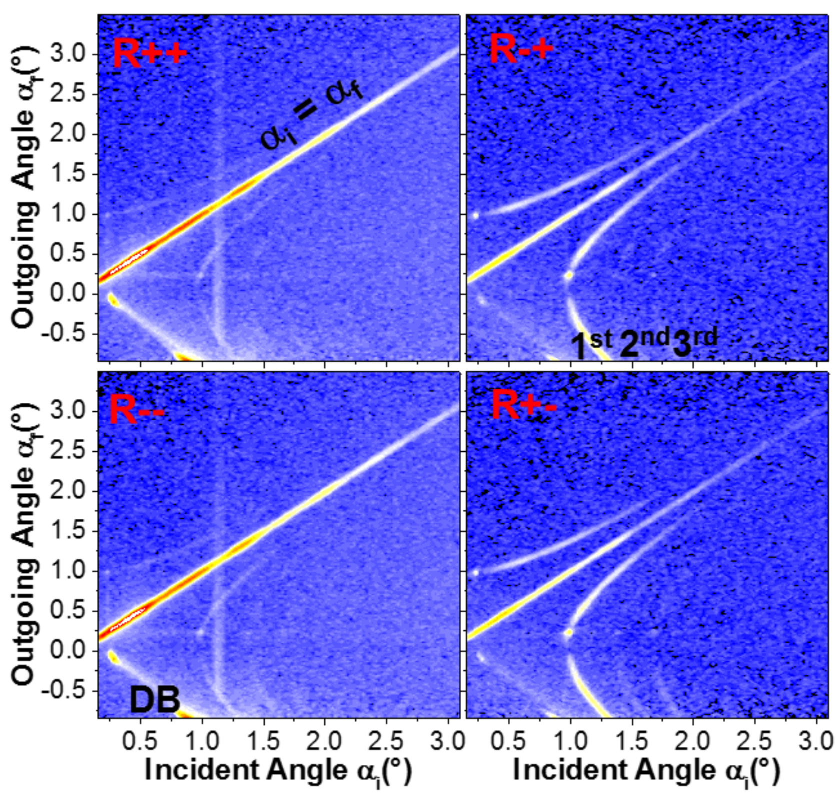

Figure 5: OSS contour plots from 2μm NiFe/IrMn stripe patterns at 3.0 mT applied along the stripes and perpendicular to the imprinted domain magnetization.