Experimental report

04/11/2024

Proposal: **5-54-397** **Council:** 4/2023

Title: Ground states and field dependenceof artificial exchange spring spirals

Research area: Physics

This proposal is a new proposal

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Samples: Au/IrMn3/NiFe/IrMn3/Cu/Si

Instrument	Requested days	Allocated days	From	To
D17	8	5	28/10/2023	02/11/2023

Abstract:

In this proposal, we aim to use polarized neutron reflectometry with polarization analysis to study the magnetization vectors of spiral spin configurations induced in exchange biased trilayer systems consisting of a single ferromagnetic layer embedded between two antiferromagnetic layers. Using He ion bombardment, the exchange coupling between the ferromagnet and one antiferromagnet is modified, leading an inversion of the unidirectional anisotropy at the two interfaces. The existence of a spiral domain state in the designed layer system during magnetization reversal was concluded from volume averaging magnetometry performed on different samples as a function of ion dose. The proposed measurements will enable us to determine the depth resolved evolution of the magnetization with different exchange bias field strengths at the opposing interfaces.

Ground states and field dependence of artificial exchange spring spirals

Experimental report: 5-54-397 on D17 (28/10/2023 – 02/11/2023)
A. Vereijken, V. Vanakalapu, C. Janzen, R. Huhnstock, T. Saerbeck and A. Ehresmann.

Scientific Background

Exchange spring spirals or magnetic helices in thin film heterostructures are typically observed by combining soft and hard ferromagnetic materials or through an exchange bias (EB) at the interface of antiferromagnet (AF) and ferromagnet (F) bilayers. These systems exhibit quasi-Bloch walls, where magnetization rotates parallel to the interface during reversal due to strong interfacial exchange coupling.

Our approach introduces a novel technique for creating spin spirals within EB AF/F/AF trilayers by aligning the unidirectional anisotropies at the two interfaces in opposing directions. This "magnetic spring" within the ferromagnetic layer is achieved by selectively inverting the EB at the upper AF/F interface using He ion bombardment (HIB), a method known to modify, for example realign, the unidirectional anisotropy in EB systems. Unlike conventional hard/soft-magnetic exchange spring systems, only a single ferromagnetic layer is present, sandwiched between two nominally identical AF layers. This may present a promising new platform for exploring tunable spin structures in thin film heterostructures.

Experiment

In this study we employed polarized neutron reflectometry (PNR) with polarization analysis to examine the depth-dependent magnetization profile in four distinct EB trilayer systems at different magnetic fields at room temperature. Using the newly commissioned analyzer on D17, we investigated samples with a consistent layer structure of Si/Cu(5 nm)/IrMn(40 nm)/NiFe(40 nm)/IrMn(40 nm)/Au(3 nm), each subjected to He-ion bombardment for reorienting the upper EB effect. The HIB variation produced varying hysteresis loop shapes, suggesting significant differences in their magnetic reversal behavior and magnetization profiles.

In this experiment, we fixed ion bombardment dose, energy and incident angle and varied only the external magnetic field direction relative to the initial EB direction. Field orientations were set to 180°, 90°, and 160°, representing expected π, π/2, and a near-π Bloch wall configuration, respectively. For the sample bombarded with a field antiparallel (Figure 1a) to the initial EB, we observed a double hysteresis loop with a plateau of field-independent magnetization, possibly suggesting a stable spiral formation over a broad field range. By contrast, the 160° samples (Figures 1b and 1c) showed a gradual magnetization transition, highlighting a different, more progressive magnetic reversal behavior. The 90° bombarded sample (not shown) behaved similarly to a conventional EB sample with an intermediate EB direction.

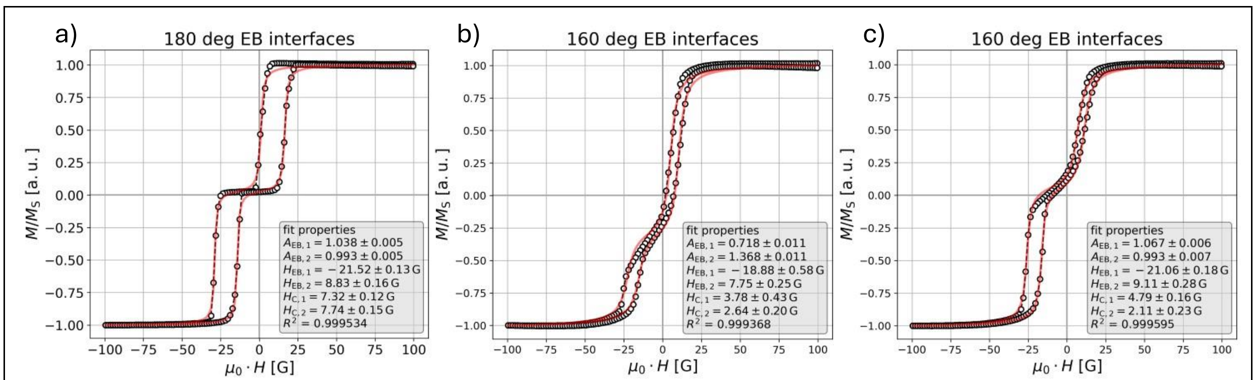

Figure 1: Example hysteresis curves of the HIB modified EB trilayers.

Results

Initial measurements in a broad q-range in saturation provided insights into the saturation magnetization, chemical morphology and interface structure (Figure 2), confirming that the performed ion bombardment had minimal structural impact.

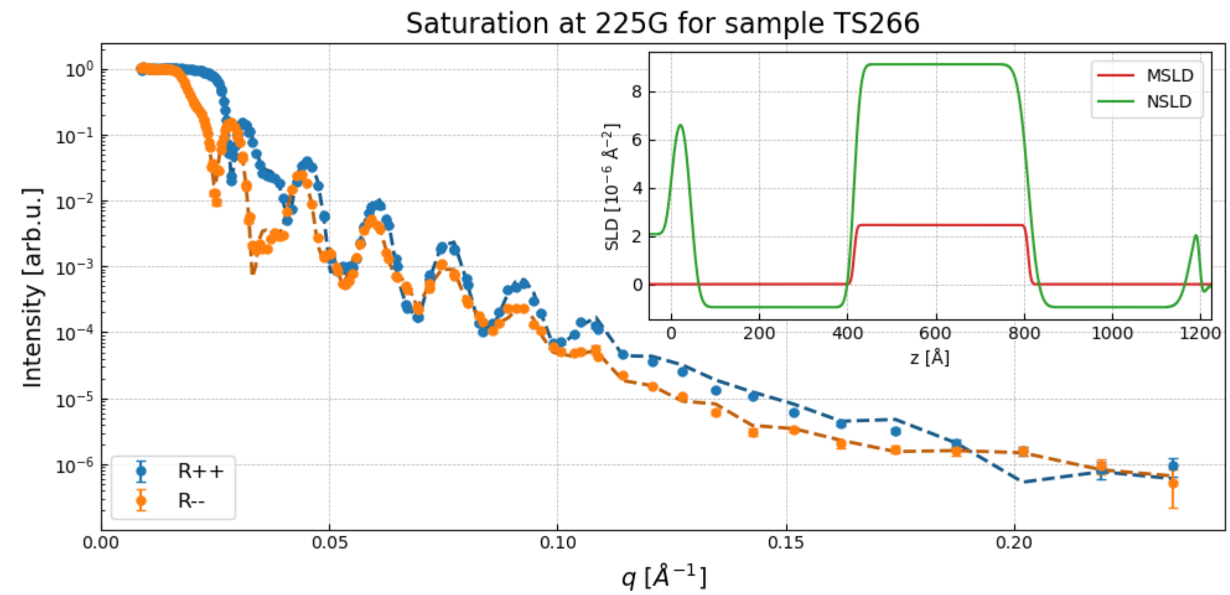

Figure 2: Saturation PNR measurement of the 160° sample TS266 with the model SLD profile obtained from the fit in the inset.

Fields near the magnetization reversal plateau (or gradual transition region) were identified through quick measurements (4 min) before being re-approached from saturation. Current analyses and simulations suggest that the formation of exchange springs competes with other states: alignment along one of the two EB orientations, their intermediate axis (especially evident in 90° and smaller angles), or decaying into a multi-domain state where the domains are aligned along the individual EB orientations. Except for the first case representing saturation, all cases were considered in analyzing the PNR curves across the magnetization reversal.

The best-fit models were obtained with a multi-domain configuration for the samples bombarded at 180° and 160° and an alignment along the intermediate (45°) axis for the 90°-bombarded sample. The absence of off-specular scattering implies that only large domains (> 30 µm) contribute to the multi-domain state. On top of the domain formation, the fit results of sample TS266 with 160° alignment suggested a small depth-dependent rotation in the magnetization profile (Figure 3).

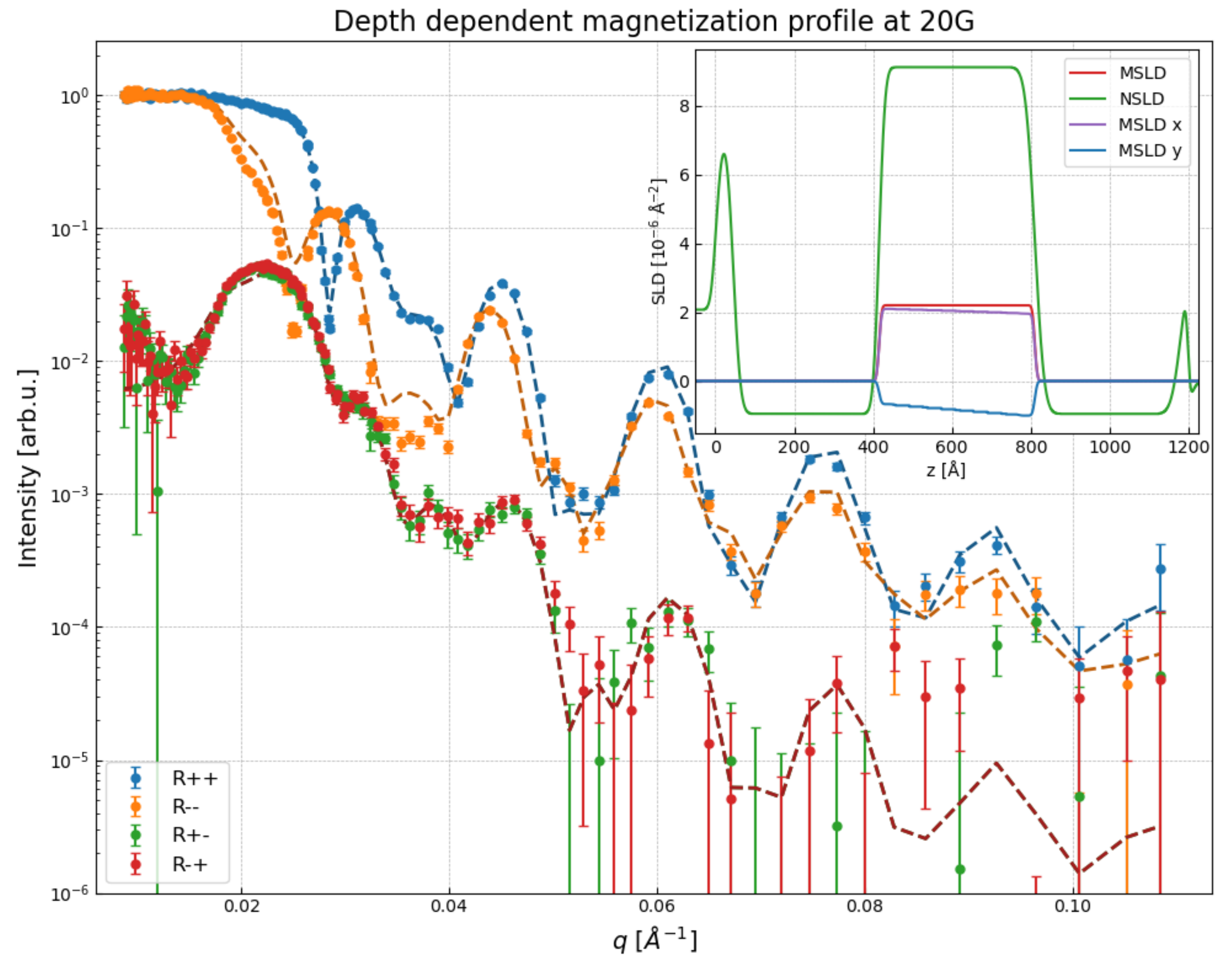

Figure 3: PNR profiles and fits of sample TS266 with 160° EB alignment at 20G after field reversal. The inset displays individual x and y projections of the in-plane magnetization indicating a small depth dependent rotation gradient.

In total 20 full measurements were obtained of four samples with different configurations. The precise analysis is ongoing, but all current models suggest a domain formation or alignment along a new intermediate EB direction as major contribution to the magnetic ground state. Even though the experiment did not yield concrete evidence of artificial exchange spirals, it provided valuable insights for future work, including a subsequent beamtime (proposal 5-72-36) at D17 and a collaboration with Prof. T Schrefl's theoretical physics group at Krems University. This cooperations aims to refine the sample design for generating artificial exchange springs and studying the general behavior in ferromagnetic layers coupled with two antiferromagnetic layers. Questions raised by this experiment, such as the independence of the EBs, possible magnetic ground states and polycrystallinity effects, are the subject of ongoing research. The results will contribute to a master's thesis where they are supported by VSM, MOKE magnetometry and MFM measurements as well as theoretical calculations. In addition to the master's thesis, the findings are going to be published in one or possibly two publications about the interaction of two differently oriented EBs on a single ferromagnetic layer.