Experimental report

16/09/2019

Proposal: **5-42-484** **Council:** 10/2018

Title: Electric field effect on the magnetic scattering of GaV4Se8

Research area: Physics

This proposal is a new proposal

Main proposer: **Sandor BORDACS**

Experimental team: Bertalan György SZIGETI
Sandor BORDACS

Local contacts: Robert CUBITT

Samples: GaV4Se8

Instrument	Requested days	Allocated days	From	To
D33	6	3	09/07/2019	12/07/2019

Abstract:

Magnetic skyrmions in non-centrosymmetric magnets are topologically stable particle-like objects. They are promissing for applications in new type of magnetic memories and logic devices, which criticaly depends on the possibilities for their control by external stimulii. The low-dissipation electric field control of skyrmion lattice state have only been demonstrated in the case of the chiral magnet Cu2OSeO3. Here, we aim to investigate the electric field effect on the modulated magnetic states of a recently discovered multiferroic skyrmion host materials GaV4Se8 using small angle neutron scattering (SANS). Recently, we demonstrated that the ferroelectric domain population in GaV4Se8 can be changed by electric poling. We are going to study if such reconfiguration of the FE domain structure affect the magnetic modulated states. We plan to detect the electric field induced changes in the structural domain population, and we will also seek for the field induced deformation or rotation of the modulated states.

Experimental report for proposal No. 5-42-484
Electric field effect on the magnetic scattering of GaV_4Se_8

S. Bordács[1], B. G. Szigeti[2], J. S. White[3], R. Cubitt[4], V. Tsurkan[2], and I. Kézsmárki[2]

[1]*Department of Physics, Budapest University of Technology and Economics, Budapest, Hungary*
[2]*Experimental Physics V, University of Augsburg, Augsburg, Germany*
[3]*Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut, Villigen, Switzerland*
[4]*Institut Laue-Langevin, Grenoble, France*

Introduction

Recently, another type of skyrmion lattice (SkL) state, the so-called Néel-type or 'hedgehog'-like SkL was found in the multiferroic GaV_4S_8 and GaV_4Se_8 using magnetization measurements, magnetic force microscopy (MFM) and small-angle neutron scattering (SANS) [1-4]. The multiferroic ground state of these compounds gives rise to strong magnetoelectric coupling that may allow new possibilities to control skyrmions [3]. Therefore, we aimed to study the effect of electric fields on the magnetic scatttering of GaV_4Se_8 in this experiment.

The magnetic building blocks of GaV_4Se_8 are tetrahedral clusters of V ions whose unpaired electron with S=1/2 spin drives a Jahn-Teller transition, and at T_s=44 K the space group symmetry is reduced from cubic (F-43m) to polar rhombohedral (R3m) [3]. Upon this structural transition 4 types of rhombohdral domains are formed with electric polarization pointing to one of the 4 symmetry equivalent <111> directions. The axial crystal symmetry in GaV_4Se_8 leads to an easy-plane anisotropy, which stabilize the SkL state down to the lowest temperatures, making GaV_4Se_8 unique among all bulk skyrmion host materials [2].

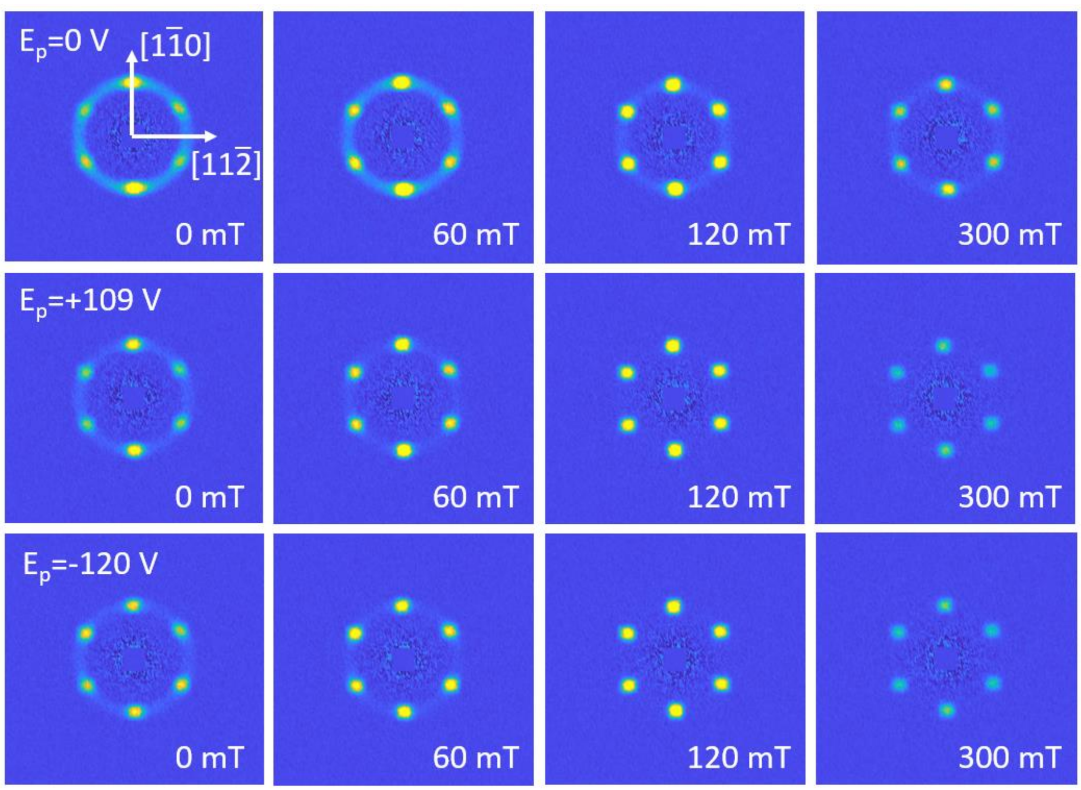

Figure 1 Magnetic field dependence of the SANS patterns measured for $\mathbf{k}_i||\mathbf{H}||[111]$ at 12 K. In each row the poling electric field E_p is the same.

Results

The SANS experiments were carried out at the D33 beamline of the ILL on a 9.2 mg GaV_4Se_8 single crystal. In order to apply electric fields along the [111] axis electric contacts are painted by silver paste on two parallel (111) faces of the crystal. Our primary aim was to determine the scattering pattern of a single ferroelectric domain sample, thus, we applied the highest available voltage on the sample at 50 K and cooled the sample through the structural phase transition. Since the resistance of the sample was 10 MΩ at 50 K ~100 V was the highest voltage that dropped between the electrodes separated by a ~ 2 mm thick sample. We refer this procedure as electric field poling. In the magnetically ordered state the electric field was switched off, and the SANS pattern was recorded at various fields.

Typical SANS images recorded at 12K are show in Fig. 1, when the incoming beam, $\mathbf{k}_i$ and the external magnetic field, **H** were both parallel to $\mathbf{k}_i||\mathbf{H}||[111]$. The scattering pattern can be divided into a ring, which corresponds to spin cycloids present in the structural domain with P||[111], and six spots around the <1-10> directions [3]. In a given domain e.g. P||[111] the cycloids prefer the <1-10> direction, thus, each of the six spots have contributions from 2 structural domains sharing the same <1-10> direction. Irrespective of the sign of the poling electric field the intensity of the ring fades out almost completely, but the intensity of the spots decreases only by 25% when the zero magnetic field measurements are compared. These finding suggest that the population of the P||[111] domain is suppressed. Surprisingly, when Ep=0, but the electric field was turned on at 12 K, we observed similar changes in the scattering pattern though polarization measurements indicate that the reversal of the ferroelectric domains is not possible at this temperature.

When SANS experiments were carried out in the $\mathbf{k}_i||\mathbf{H}||[001]$ configuration a non-trivial pattern appear in scattering images even in the paramagnetic phase at 20 K as shown in Fig. 2. (Here the background was collected above the structural phase transition at 50 K.) Several peaks appear along the <1-10> and <001> direction and their intensity is enhanced when finite poling electric field is applied. These structures might come from the scattering on the lamellar structure of the ferroelectric domains, which was observed by piezoresponse force microscopy (PFM) in GaV_4S_8 [5]. The domain walls are only {001} type planes according to the PFM measurements, which cannot explain the <1-10> peaks given that those are not artefacts created by multiple scattering as confirmed by rocking scans. Another anomaly is that all peaks become more intense while keeping their position when a poling electric field was applied. This is in contrast to the expectation that the number of domain walls should be the same or less when the population of one of them is suppressed.

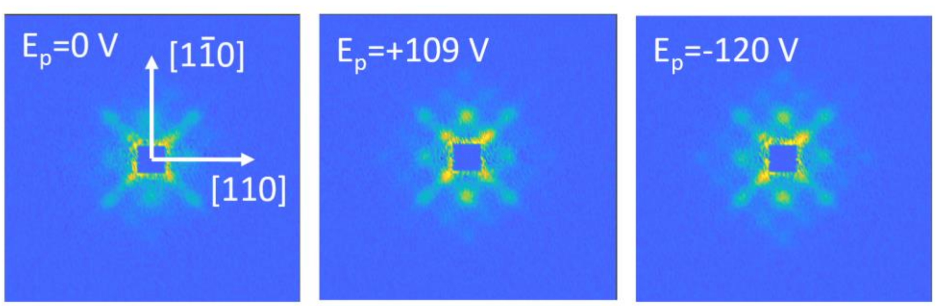

Figure 2 SANS patterns measured for $\mathbf{k}_i$||H||[111] at 20 K in the paramagnetic phase after poling the sample with different electric fields.

References

[1] I. Kézsmárki *et al.*, Nat. Mater. **14**, 1116 (2015).
[2] S. Bordács *et al.,* Sci. Rep. **7**, 7584 (2017).
[3] E. Ruff *et al.*, Sci. Advances **1**, e1500916 (2015).
[4] J. S. White et al., Phys. Rev. B 97, 020401(R) (2018).
[5] Á. Butykai et al., Sci. Rep. 7, 44663 (2017).