Cryogenic TEM Studies of Bloch and Néel Skyrmion Textures in Lacunar Spinels and Cubic Helimagnets

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Skyrmions are stable topological defects with a complex non-coplanar spin structure, which distinguishes them from magnetic domain walls and vortices [1-4]. They are promising candidates for magnetic memory devices, because of their small size, thermal stability and high mobility. Here, the several types of skyrmions, namely Bloch-, Néel-, and Anti-skyrmions, exhibit differences in their formation kinetics, their behavior in the presence of geometric boundaries as well as their transport properties because of their different spin texture rotation. Accordingly, a thorough understanding of the spatial distribution of the skyrmion texture is indispensable to foster the field. Indeed, a substantial proportion of magnetic skyrmion textures occur at (very) low temperatures only. This particularly includes the recently observed Néel skyrmions in the lacunar spinel $GaVa_4S_8$ occurring at 13K [5] but also Bloch skyrmions in FeGe stabilizing around 280K [6]. Cryogenic conditions render the direct mapping of magnetic spin texture by electron holographic methods challenging, in particular if liquid He cooling or tomographic tilt series acquisition is required.

Here, we present our recent cryogenic TEM studies of different skyrmion hosting materials. To address the low temperature regime in the lacunar spinels, we employ our dedicated cryogenic JEOL JEM 2010F IFW special, which allows adjusting and maintaining any temperature ranging from room temperature down to 7K for days. Bulk GaV_4Se_8 is predicted to show a structural transition from cubic to orthorhombic structure (Jahn-Teller-distortion) at a temperature of 42K and Néel type skyrmions below 18K under applied magnetic field between 0.10T and 0.45T.[7] Here the latter couple to the ferroelectric polarization axis pointing into the [111]-direction of the cubic room temperature phase. In order to study this multiferroic coupling, we characterized the cycloidal and skyrmionic phase in thin GaV_4Se_8 lamellas of different crystallographic orientation in dependence of temperature and applied magnetic field. We identify magnetic textures that are not considered in the bulk phase diagram (see Bordács et *al.* [7]). We discuss the origins of these in terms of crystal symmetries and strain prevailing in the thin film slab geometry.

FeGe is a well-studied skyrmion hosting material with cubic B20 symmetry [6]. Electron tomography studies are carried out at a FEI Titan^3 microscope at liquid nitrogen temperatures to reveal the formation of 3D spin textures at surfaces of FeGe. We acquired cryogenic tilt series of off-axis holograms in order to reconstruct the projected in plane magnetic induction of the helical phase under various projection angles. In a second step, we compare this data to various surface modulations of the skyrmion texture, e.g., the chiral surface twist. Our results suggest the formation of a, to our best knowledge, so far not yet predicted and explored surface modulation.

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[8] We acknowledge funding from the European Research Council (ERC) under the Horizon 2020 research and innovation programme of the European Union (grant agreement No 715620)

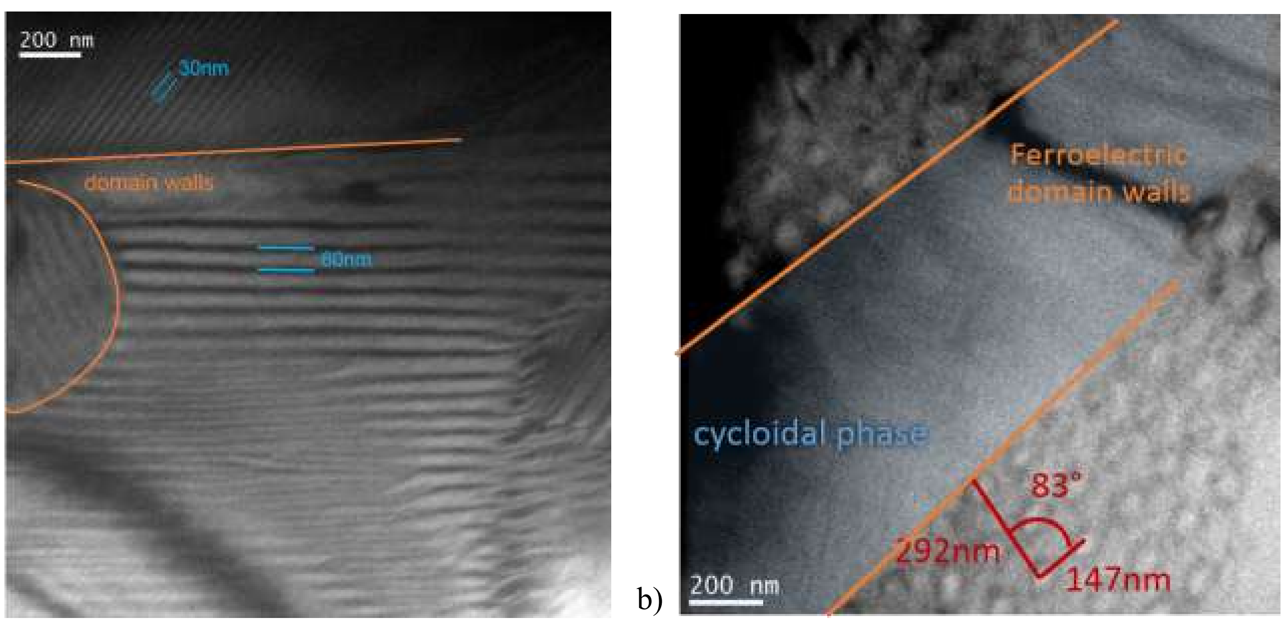
a)


Figure 1. a) Cycloidal phase of GaV_4Se_8 cut in <111> direction at 10K and 160mT: different sizes of the cycloidal phase are clearly visible; b) ferroelectric domains in GaV_4Se_8 cut in <110> direction: ferroelectric domain walls separate cycloidal and skyrmion phase from each other