Experimental report

10/09/2019

Proposal: **5-54-234** **Council:** 10/2016

Title: Study of the electric field control of magnetic domain population in the E-type phase of strained (010) oriented o-LuMnO3 films using spheri

Research area: Materials

This proposal is a new proposal

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Local contacts: Mechthild ENDERLE

Samples: $LuMnO_3$

Instrument	Requested days	Allocated days	From	To
IN20 CPA	10	9	03/10/2018	12/10/2018
IN3	0	1	02/10/2018	03/10/2018

Abstract:

We want to determine electric(E) -field dependence of the magnetic domain population in the E-type phase of multiferroic and strained orthorhombic (o-) $LuMnO_3$ thin film, deposited on (010) oriented o-$YAlO_3$ substrate. In our recent polarized neutron scattering study on IN20 without E-field, we observed the film to display an intrinsic, presumably related to film-strain, domain imbalance in the E-type phase of the o-$LuMnO_3$ film; namely a 60% E1-domain population over 40% E2-domains. . Here we plan to apply an E-field to tune and study the imbalance of the domain population and provide direct proof of magneto-electric coupling in the $LuMnO_3$ film. We will employ the same polarised neutron device CryoPAD set up on IN20 to measure the domain population fraction (E1/E2) under various E-fields. The sample to be measured is a 100 nm thick (010) oriented o-$LuMnO_3$ film.

Proposal number: 5_54-234 (Instrument : IN20)
E-field induced population inversion of magnetic domains in *E*-type $LuMnO_3$ thin films

Investigators: Saumya Mukherjee, Mechthild Enderle, Laurent Chapon, Christof Niedermayer.

Motivation and earlier studies

Recently, we found that depending on application of strain the multiferroic properties of orthorhombic o-$RMnO_3$ films gets drastically modified independent of the R-ion radius. The robust multiferroic ground state is characterized by antiferromagnetic (AFM) *E*-type ordering of Mn spins and a large ferroelectric polarization along *a* axis. We selected a 100 nm thick $LuMnO_3$ (0 1 0) oriented film with non-magnetic R-ion to focus solely on the magnetic properties related to the Mn-ion ordering. In earlier studies, non-polarized neutron diffraction showed that the transition to the antiferromagnetic phase occurs at T_N ~ 39 K with incommensurate (ICM) order and periodicity of q_{ICM} ~ 0.478 r.l.u, and represents the high temperature incommensurate phase. On cooling, at T~29 K a commensurate phase appears with q_{CM} ~0.5, which coexists with the ICM phase. In the present study we focussed on studying the magneto-electric coupling between the CM order and the ferroelectric order. The CM phase is described by *E*-type order has equivalent magnetic domains E_1 and E_2. These domains are characterized by spin orientations up-up-down-down (E_1) and up-down-down-up (E_2) at Mn sites [(1/2, 0, 0), (0,1/2,0), (1/2, 0, 1/2), (0, 1/2, 1/2)], respectively. We aimed at switching between these two domains and change dominant contributions to the magnetic intensity by reversing the polarity of the external electric potential. This will confirm the magneto-electric coupling between the ferroelectric order and the CM order. For this we used spherical neutron polarimetry (SNP) and measured the polarization matrix at q_{CM} ~ 0.5 for positive, negative and zero field. A set of polarization matrix elements were measured.

Results

SNP has the ability to perform full polarization analysis of the scattered magnetic intensity along all three axis (x,y,z) in the laboratory frame. For our studies the experimental geometry is defined with the scattering vector **Q** parallel to x-axis and perpendicular to y-axis, such that the x-y plane corresponds to the horizontal scattering plane and the z axis is normal to the scattering plane. Different combinations of polarization of the spins of the incident and scattered neutron beam is defined with respect to the polarizing and analysing magnetic field. For example, with an incident beam with spins of neutrons polarized along x, $P_0 \parallel x$ and a scattered beam with $P_1 \parallel$ - x, the measured intensity is described by $S_{x\,-x}$. Similarly, we measured magnetic intensities : $S_{-x\,x}$, $S_{x\,x}$, $S_{y\,y}$, $S_{-y\,y}$, $S_{z\,z}$, $S_{-z\,z}$, $S_{z\,y}$, $S_{z\,-y}$, $S_{-y\,-z}$, $S_{-y\,z}$, where the first (second) subscript represents the incident (scattered) spin polarization as shown in Fig. 1 (a-g).

We applied electric field of +/- 15 kV/cm by depositing Au pads on the sample surface such that the field is applied along the ferroelectric polarization axis $\parallel a$ as shown in Fig. 1h. From the measured intensity the polarization matrix elements ($P_{i\,j}$: $i,j = x,y,z$) are derived, which are sensitive to the domain population ratio. We presented here a schematic of the measured value in the form of the histogram showing the variation of these elements and how they vary as a function of the field (Fig. 1i). We can clearly see that the positive bias shows more prominent effect w.r.t the zero bias field scenario (Fig. 2). For negative bias, E_2 domain is more dominant than E_1 and the condition flips with positive bias. This work highlights the capability of SNP to probe thin films and unambiguously probe the magnetic domains. Application of E-field demonstrated the coupling of magnetic and electric order parameter successfully. We belief our studies will excite to perform similar challenging experiments on low dimensional systems with limited neutron scattering.

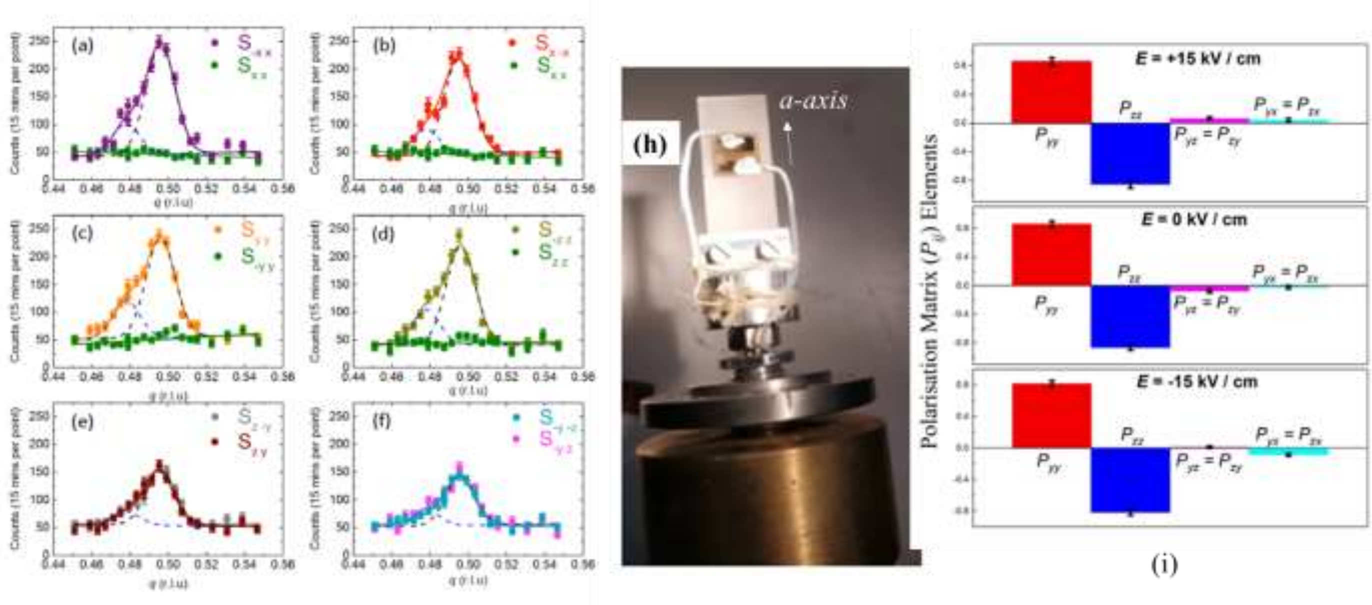

Fig. 1: (a-f) Measured magnetic intensity along different polarization channels, (h) Image of the sample showing electrode connections for application of the electric field and (i) Histogram showing the polarization matrix elements measured under application of E-field.

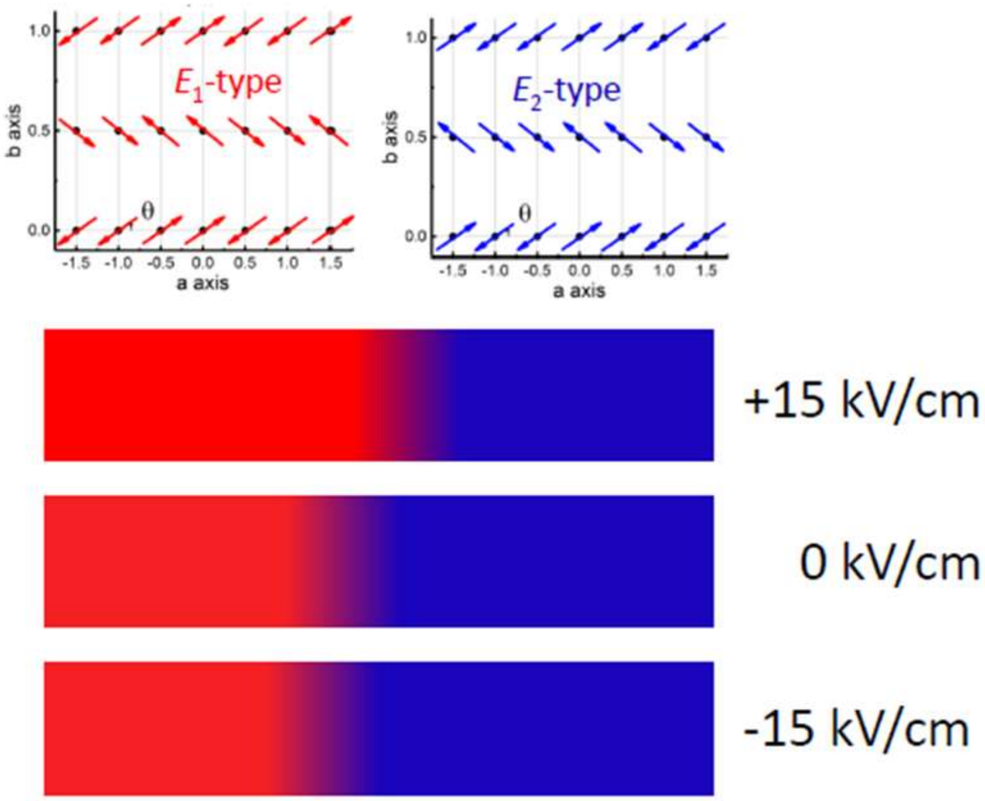

Fig. 2: Showing schematic of the spin orientations for E_1 and E_2 domains and how the relative domain contribution to magnetic intensity vary with application of electric field.