Magnetic order in Cr-doped $Sb_{2-x}Te_3$ topological insulator thin films

N.-J. Steinke[1], P. J. Baker[1], L. Duffy[1,2], G. van der Laan[3], Z. Salman[4], S. Langridge[1], T. Hesjedal[2]

[1] ISIS neutron and Muon Source, Rutherford Appleton Laboratory, United Kingdom

[2] University of Oxford, United Kingdom

[3] Diamond Light Source, Rutherford Appleton Laboratory, United Kingdom

[4] SμS, Paul Scherrer Institut, Switzerland

The most common route to attempt time-reversal symmetry breaking in topological insulators (TIs) is to introduce magnetic order near the surface, either by magnetic doping of the TI or by proximity coupling with a ferro-, ferri- or antiferromagnetic layer. However, the nature of the magnetic ordering in transition metal doped magnetic TIs remains poorly understood. In particular the homogeneity and robustness of the magnetic ordering has been under debate and various types of magnetic order have been proposed [1-8].
Here we concentrate on the nature of the ferromagnetic ordering of Cr-doped $Sb_{2-x}Cr_xTe_3$ which have a remarkably high T_C of up to 186K and a magnetic moment per Cr atom of $2\mu_B$ [9], weakly dependent on doping concentration.

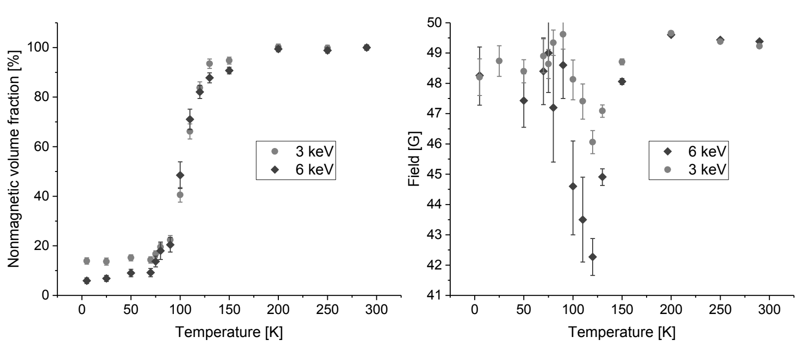

Figure: Magnetic volume fraction and total field dependence on temperature of a $Cr_{0.4}Sb_{1.6}Te_3$ thin film as studied by low energy μSR, circles near the surface and diamonds deep in the film.

Our samples are 100 nm thin films grown by molecular beam epitaxy with a Te overpressure on c-plane sapphire substrates. Reflection high-energy electron diffraction monitoring during growth show streaky patterns indicative of 2D growth. XRD measurements show well-ordered films with the c-axis out-of-plane and a reduction of the c-axis lattice parameter with increasing doping concentration, Figure 1. No parasitic phases were detected up to doping concentrations of x=0.42. SQUID magnetometry shows a T_C strongly dependent on doping concentration and polarised neutron reflectometry measurements give a magnetic moment of $2\mu_B$/Cr-atom and no inhomogeneity in the magnetisation depth profile in the samples investigated. [9]
XMCD measurements reveal carrier mediated ferromagnetic order [10], similar to the findings on $Cr_x(Sb,Bi)_{1-x}Te_3$ [11]. Despite this, proximity coupling to an adjacent Co layer is surprisingly weak [10].

We used low energy muon spin relaxation (μSR) spectroscopy to probe the local magnetic order in $Cr_xSb_{2-x}Te_3$ comparing two different doping concentrations. Weak transverse field measurements allow us to map the transition as a function of temperature and implantation depth and to estimate the magnetic volume fraction as a function of these parameters. Our measurements show a clear ferromagnetic transition with peaks in the relaxation rate at 90K and 110K for the two doping concentrations, see Figure. In addition, there is a clear dip in the internal magnetic field around the ferromagnetic transition the size of which depends on the doping concentration. This may indicate that the ferromagnetism in these samples develops inhomogeneously with the details depending on the concentration and also on muon implantation depth. The signal is larger at implantation depths deep in the film compared to close to the film surface. We will present a detailed analysis of temperature and depth dependence of the ferromagnetic transition.

References

[1] Yu et al., Science **329**, 61 (2010);
[2] Li et al., PRL **114**,[3] 146802 (2015);
[3] Chang + Li, J. Phys.: Cond. Mat. **28**, 123002 (2016)**;**
[4] Choi et al., JAP **109**, 07E312 (2011);
[5]Chang et al. PRL **112**, 056801 (2014);
[6] Peixoto et al., PRB **94**, 195140 (2016);
[7] Vergniory et al., PRB **89**, 165202 (2014);
[8] Lachman et al., Sci. Adv. 1, e1500740 (2015);
[9] L. J. Collins-McIntyre et al., Europhys. Lett. **115**, 27006 (2016);
[10] L. B. Duffy et al., PRB in press (2017);
[11] Ye et al., Nat. Commun. **6**, 8913 (2015);