Experimental report

01/06/2017

Proposal: **5-54-203** **Council:** 4/2015

Title: Magnetic ordering at the Verwey transition in bulk like Fe3O4 thin films

Research area: Physics

This proposal is a new proposal

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Samples: Iron oxide (Fe3O4) on Yttria-stabilized zirconia (YSZ)
Iron oxide (Fe3O4) on strontium titanate (SrTiO3)

Instrument	Requested days	Allocated days	From	To
D17	8	5	10/06/2016	15/06/2016
SUPERADAM	8	0		

Abstract:

Magnetite (Fe3O4) is a predicted half-metallic (100% spin polarised) ferromagnet with a high Curie temperature of ~858 K. These properties make it well suited to use in spintronic applications such as magnetoresistance-based devices and spin injection into semiconductors. In bulk magnetite, the Verwey transition is a well-studied phenomenon although still debated. Thin film investigations have been hindered by the formation of growth defects and strain, leading to antiphase boundaries an altered magnetic properties. We have developed an optimised growth method for producing Fe3O4 thin films with bulk-like stoichiometry and properties. Consequently, this provides a unique opportunity to study the magnetization depth dependence through the transition. We also wish to locate magnetic interfacial properties and investigate them as a function of strain. The results will clarify the role of strain and different interface properties on the density of defects, such as anti phase boundaries, and point the route to device fabrication.

Magnetic ordering at the Verwey transition in bulk like Fe_3O_4 thin films

5-54-203

Abstract:

The Verwey transition, observed in magnetite (Fe_3O_4) at T_V ~ 120 K [1], is a prototypical metal-insulator transition but is still not fully understood [2,3]. Fe_3O_4 is a half-metallic ferromagnetic material with, in principle, 100% spin polarization at the Fermi level and it exhibits a high Curie temperature of T_C ~ 858 K. These properties make Fe_3O_4 a promising ferromagnetic electrode for tunnelling magnetoresistance (MR) based devices and for spin injection into semiconductors. However, these unique properties, which are relevant for spintronic device applications, have been difficult to realize in thin-film form (necessary for devices) owing to the formation of growth defects, the presence of interfacial strain and non-stoichiometry. These defects also hamper observation of the Verwey transition. We wish to study the magnetic profile of the Fe_3O_4 layers above and below T_V, paying particular attention to changes in magnetisation due to interfacial strain and possible twin defects [4].

Experimental details:

Samples of Fe_3O_4 (80 nm) grown on MgO(111) and YSZ(111) substrates, were measured with time of flight (TOF) polarised neutrons at temperature ranges between 30 K and room temperature with an external magnetic field ~ 2 T. We measured from Q = 0.01 to Q = 0.16 in order to be sensitive to magnetization changes at the substrate/film interface. Changes in sample resistance were taken in situ, enabling measurements in precise transitional locations and the ability to calibrate with different low temperature measurements in the future.

Results:

Preliminary fitting of the data shows that for a sample annealed at high temperatures (950 °C, Figure 1), the Fe_3O_4 layer is uniform in composition and density where substrate and surface layers are abrupt. There is an increase in magnetic moment below the Verwey temperature, however the shape of the magnetic profile remains the same.

For a sample annealed at 400 °C (Figure 2), we find a large varying change in composition or density (currently uncertainty is due to the coupling of these parameters) over the Fe_3O_4 film. An increase in magnetism is again seen below T_V, but a difference in the surface magnetism is observed at all different temperatures above, on and below T_V.

Future work:

Refined fitting simultaneously with X-ray reflectivity is needed to ensure correct decoupling of compositional and density information in order to extract a reliable magnetic profile.

Temperature dependant X-ray diffraction data will be analysed in order to see how the change in magnetic moment below T_V is correlated to the change crystal structure at these lower temperatures.

Results from this data will be used in order to write a research paper demonstrating the differences in magnetic and structural profiles for different post-growth annealing temperatures.

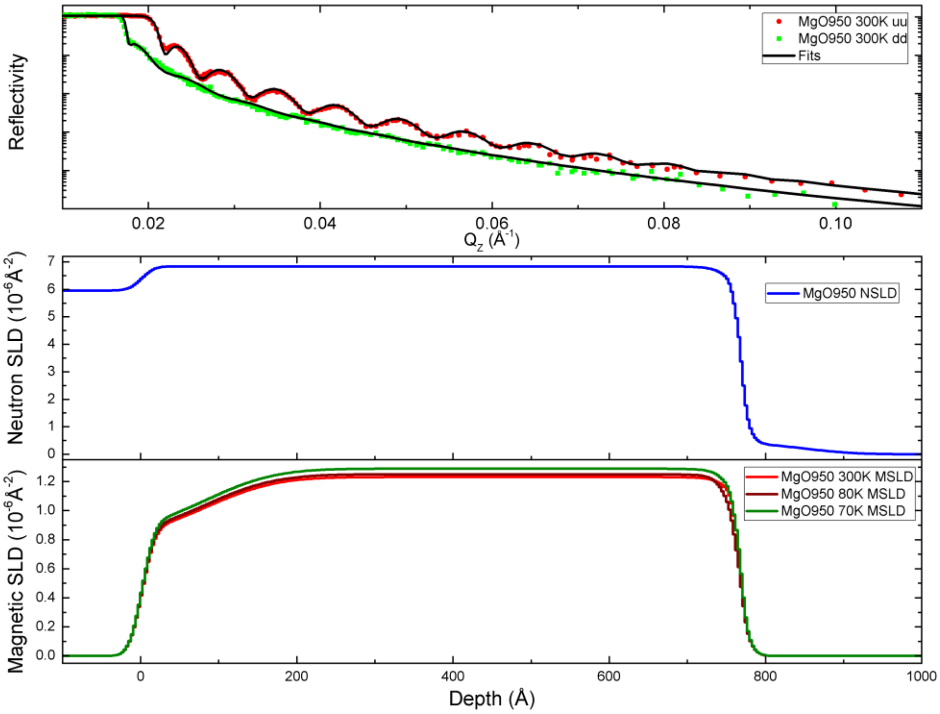

Figure 1: PNR data, fits, and corresponding scattering length and magnetic scattering length densities of Fe_3O_4 sample grown on MgO(111) substrate and post-annealed at 950 °C in a mixed gas of CO and CO_2 [5].

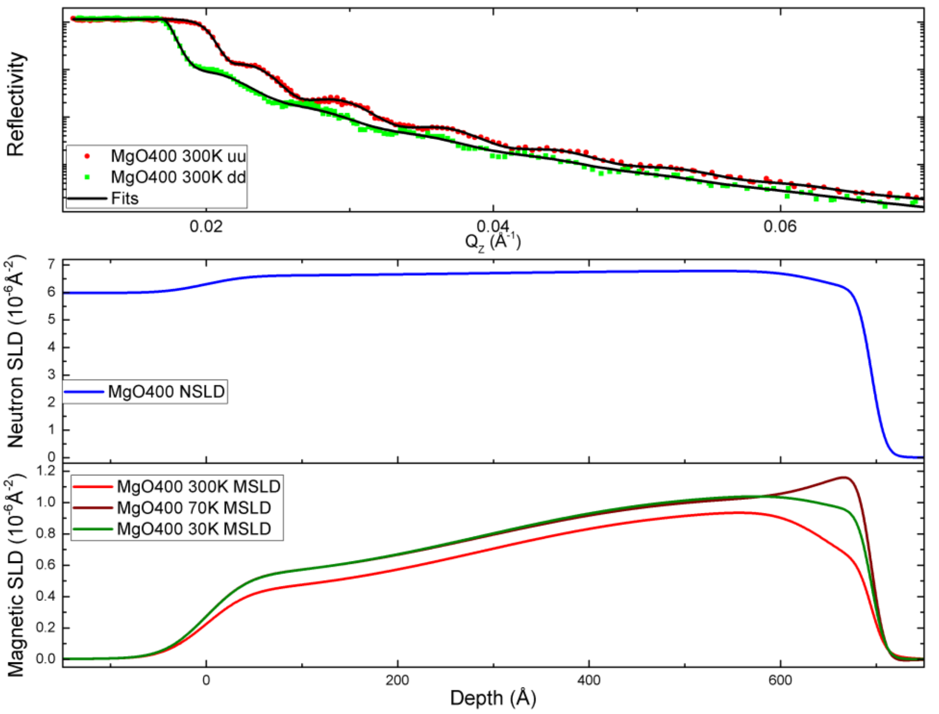

Figure 2: PNR data, fits, and corresponding scattering length and magnetic scattering length densities of Fe_3O_4 sample grown on MgO(111) substrate and post-annealed at 400 °C in a mixed gas of CO and CO_2 [5].

References:

[1] E.J.W. Verwey, Nature (London) 144 (1939) 327.
[2] M. S. Senn, J. P. Wright, and J.P. Attfield, Nature, 481, 173–176 (12 January 2012)
[3] P. Piekarz, K. Parllinski, and A. Oles, Phys. Rev. Lett., 97, 156402 (2006)
[4] D Gilks, L Lari, K Matsuzaki, R Evans, K McKenna, T Susaki, V K Lazarov, Journal of Physics: Conference Series 522 (2014) 012036
[5] K. Matsuzaki, H. Hosono and T. Susaki, APEX, 6, 073009 (2013)