Polarised Neutron Reflectometry Measurements on a $YBa_2Cu_3O_7$ / $La_{2/3}Ca_{1/3}MnO_3$ Superlattice at Different Positions of the Hysteresis Loop

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Polarised neutron reflectometry (PNR) measurements have been used to determine the magnetisation reversing process of a superlattice with 8 $YBa_2Cu_3O_7$ (256 Å) / $La_{2/3}Ca_{1/3}MnO_3$ (256 Å) double layers when driving a hysteresis loop from H_{appl} = −7 T to +7 T at T = 5 K. Due to the experimental set-up, only one branch of the hysteresis loop was accessible with the neutrons while a sample magnetisation in both direction was possible: Any zero field point in the neutron flight path would depolarise them, which limits in case of a fixed guide field and a fixed polariser the accessible field range to fields in only one direction. Additional limitations can occur if the stray fields of the magnet become larger than the guide field, leading to zero field points in the neutron flight path.

In our case, we needed access to a very broad field range, as a high magnetic field of about 7 T is needed to saturate the ferromagnetic layers and as the coercive field of Hcoerc = 0.0282 T is relatively small. We used a guide field installed from the polariser to the magnet coils, which compensated the stray field of the magnet in the case of small applied fields (H_{appl} < 0.1 T). In the case of larger fields (H_{appl} ≥ 0.1 T), a different set-up was used: The neutrons were kept polarised by the stray field of the magnet, which needed to be along the same direction as the guide field in the small-field set-up. This means the accessible field direction at the sample position was opposite to the accessible field direction in the small-field set-up. In the large-field set-up, the neutrons were kept polarised within the cryomagnet by driving the two helmholtz coils in asymmetric mode (different currents in the two coils) to avoid any zero magnetic field point in the neutron flight path. Due to this field arrangement, the neutrons performed a spin turn of π on their way through the magnet to the sample position [1]. This large-field set-up could not be used for small fields because the guide field to turn the neutron spin on the way through the magnet becomes too small. Therefore, the measurements presented here were performed at two sides of the hysteresis loop. The sample was first cooled to 5 K in zero field and then saturated in a magnetic field of H_{appl} = +7 T. The reversing process has then been investigated in the negative field range to fields down to -0.053 T in the small-field set-up. After a saturation at -7 T, measurements at increasing field strengths from +0.1 T to +6 T have been performed to access the larger field strengths of the hysteresis loop in the high-field set-up. Hysteresis effects have then been investigated at the same applied fields after the saturation in +7 T. One additional measurement was performed at +0.008 T in order to get an insight in the magnetic profile almost in remanence.

The magnetisation reversed mainly between H_{appl} = −0.023 T and -0.033 T which corresponds well to the macroscopically measured coercive field of H_{coerc} = −0.0282 T. During the reversing process, no additional Bragg peaks appeared and no double-step edge of total reflection was observed (see Figure 1). The first observation excludes the possibility of single layers reversing their magnetisation one after the other, while a uniform rotation of the layer magnetisation or of large magnetic domains as described in [2] could be excluded by the latter observation.

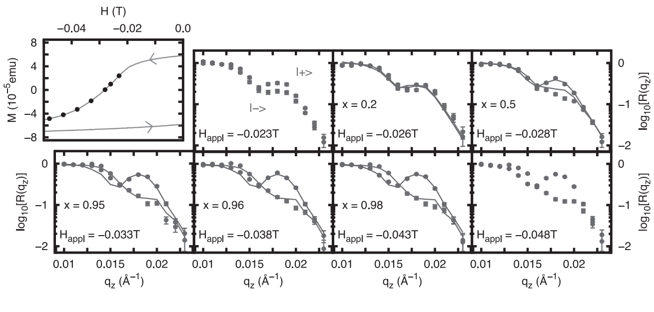

Fig. 1 Top left: Hysteresis loop as measured by macroscopic magetometry measurements. The black dots are the points where the reflectivity curves shown in the rest of the figure have been taken. Rest: Reflectivity curves measured at different magnetic fields showing the reversion of the magnetisation. The Reflectivity curves measured in the range of H_{appl} = −0.023 T to H_{appl} = −0.048 T could be reproduced with Equation 1. The dots with error bars show the measurements while the lines show the linear combination.

Theoretical reflectivity curves from model magnetic field profiles were calculated and compared with the measurements. No matching field profile was found for the measurements with an applied field in the range of H_{appl} = −0.026 T to -0.043 T where the magnetisation reversion mainly takes place, even though it is possible in this field range to reproduce the measurements with a linear combination of the curves measured at -0.023T and -0.048T with the formula:

$$1).\quad R^{+/-} = (1-x)\, R^{+/-}_{-0.023T} + x \cdot R^{+/-}_{-0.048T} \,.$$

Here R^+ and R^- indicate the reflectivities for spin up and spin down neutrons, respectively (Figure 1). The representation of the transition from H_{appl} = −0.023 T to −0.048 T as a linear combination is a strong indication that there are large magnetic domains reversing their magnetisation one after the other. These domains scatter incoherently between each other as no average field profile could be found when modelling. Therefore these domains must be larger than the lateral neutron coherence length of about 100 μm.

At higher fields, theoretical models were found to reproduce the measured data reasonably well. Figure 2 shows reflectivity curves taken at 0.1 T after saturation in -7 T and +7 T, respectively and at 0.4 T after saturation in -7 T. For all curves, very similar models were found with a magnetisation of about 0.61 T in $La_{2/3}Ca_{1/3}MnO_3$. After saturating in -7 T, a 12.5 Å thick $La_{2/3}Ca_{1/3}MnO_3$ layer at the interfaces contains an anti-parallel oriented magnetisation of -0.043T at H_{appl} = 0.1 T and no magnetisation at H_{appl} = 0.4 T. After saturation in +7 T, the nonmagnetic layer persists at H_{appl} = 0.1 T, even with a thickness of 15 Å.

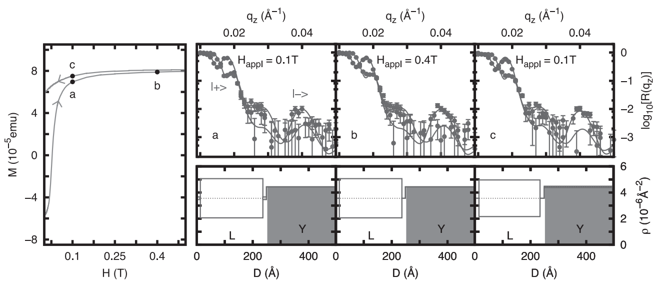

Fig. 2 Left: Hysteresis loop measured with macroscopic magnetometry with the field positions where PNR curves were measured. (a,b) Reflectivity curves as measured at H_{appl} = 0.1 T and 0.4 T after saturation in -7 T compared to the calculated models. (c) Reflectivity curves as measured at H_{appl} = 0.1 T after saturation in +7 T compared to the calculated model. Models: Depth profile of the potential seen by the |−⟩ and |+⟩ neutrons (grey and black). The models contain a reduced density for the two top layers.

After saturation in +7 T, a small anti-parallel moment of -0.022 T was observed in $YBa_2Cu_3O_7$. The anti-parallel moment in $YBa_2Cu_3O_7$ could be resulting from pinned vortices that developed at high fields in order to expel the external field of the superconductor. The nonmagnetic or anti-parallel oriented layer at the $La_{2/3}Ca_{1/3}MnO_3$ interfaces has been described in earlier publications as a possible magnetisation profile at small applied fields of a few 10 mT [3].

References

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