Polarised Neutron Reflectometry Studies of $YBa_2Cu_3O_{7-\delta}/La_{2/3}Ca_{1/3}MnO_3$ Multilayers

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Multilayers of the high-T_c superconductor $YBa_2Cu_3O_{7-\delta}$ and the CMR ferromagnet $La_{2/3}Ca_{1/3}MnO_3$ show an unexpected deviation of the magnetization topology with respect to the nuclear one. Polarized neutron reflectometry measurements were used to deduce the vertical field distribution as a function of the temperature. This change in topology occures between the superconducting and the ferromagnetic transition temperature.

In previous experiments multilayers of the high-T_c superconductor (SC) $YBa_2Cu_3O_{7-\delta}$ (YBCO) and the colossal magnetoresistance ferromagnet (FM) $La_{2/3}Ca_{1/3}MnO_3$ (LCMO) have been investigated to deduce the vertical profile of the in-plane magnetic induction. Clear evidence was found, that the magnetic induction does not show the same topology as the nuclear structure [1, 2].
The investigations were repeated with more appropriate samples (increased number of bilayers, larger layer thicknesses) and a more elaborate measuring scheme. The results presented here were taken on a $[\mathrm{YBCO}(200\,\text{Å})/\mathrm{LCMO}(200\,\text{Å})]_8/SrTiO_3$ sample.

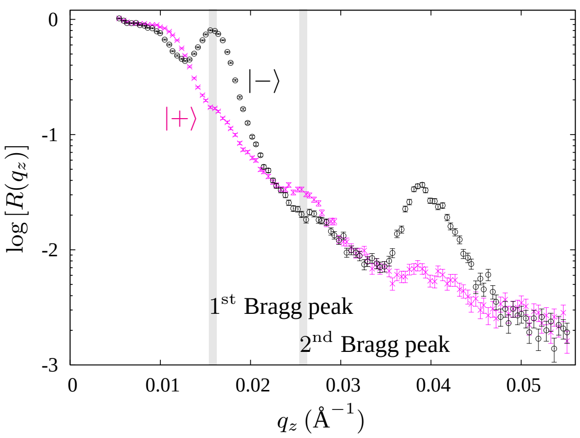

Figure 1: Reflectivity for $|-\rangle$ (*black balls*) and $|+\rangle$ (*grey crosses*) neutrons at $T = 15\,\mathrm{K}$. The sample was field-cooled and measured at $H = 100\,\mathrm{Oe}$.

Fig. 1 shows polarized specular reflectivity measurements at a temperature well below the superconducting transition temperature T_c. The structurally forbidden 2^{nd} Bragg peak appears due to the different topology of the magnetic induction compared to the nuclear profile [1, 2]. The magnetic induction is no longer constrained to the LCMO layer. To investigate the temperature dependence of this effect, polarized measurements of the maximum intensity of the 1^{st} and the 2^{nd} Bragg peak were performed (see Fig. 2).
The intensity increase of the $|-\rangle$ and the decrease of the $|+\rangle$ neutrons of the 1^{st} Bragg peak are caused by the increasing magnetic induction in the LCMO-layers below $T_{\mathrm{Curie}} \approx 240\,\mathrm{K}$. We assume that the initial weak increase of the peak intensity at T_{Curie} (equal for both neutron spin states) of the 2^{nd} Bragg peak is driven by a magnetic roughness. Below a temperatur T', well above T_c, the intensities for the two spin states split. This splitting reaches its maximum when approaching T_c.

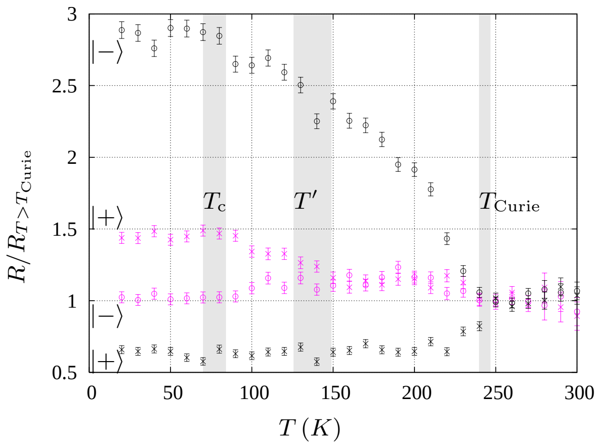

Figure 2: Reflectivities at the positions of the 1^{st} ($q_z = 0.007\,\text{Å}^{-1}$, *black*) and 2^{nd} ($q_z = 0.017\,\text{Å}^{-1}$, *grey*) Bragg peaks for neutrons in the spin states $|+\rangle$ (*crosses*) and $|-\rangle$ (*balls*) as a function of temperature. The sample was field cooled and measured at H = 100 Oe. See also Fig. 1. The reflectivities are normalised at $T > T_{\mathrm{Curie}}$. The grey bars give the temperature ranges for the transtition temperatures T_{c} and T_{Curie}, and for the onset T' of the splitting of the 2^{nd} Bragg peak intensities.

The comparison with simulated reflectivity curves allows the identification of two possible magnetisation profiles: a sizable magnetic moment within the SC layer antiparallel to the one in the FM layer, as proposed by F.S. Bergeret [3], or a ”dead” region in the FM layer with zero net magnetic moment.
Since the splitting of the two spin states occures at a temperature well below T_{Curie}, the profile with a magnetic dead layer is highly unlikely. We therefore propose an antiphase magnetic proximity effect as described in [1]. A possible explanation for the occurence of this effect above T_c may be found in terms of strong SC fluctuations in that temperature range which are well known to be prominent in underdoped high-T_c superconductors.

[1] J. Stahn *et al.*, *cond-mat*/0408311 (2004).

[2] J. Stahn *et al.*, *PSI Scientific Report 2003 III*, 66.

[3] F.S. Bergeret *et al.*, *Europhys. Lett.*, **66**, 111 (2004).

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