Magnetic Field Distribution in High T_c SC / FM Multilayers

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Multilayers of the high T_c superconductor $YBa_2Cu_3O_7$ (YBCO) and the GMR ferromagnet $La_{1/3}Ca_{2/3}MnO_3$ (LCMO) showed unexpected magnetic behaviour in Low Energy μSR and magnetisation measurements. To deduce the field distribution as function of field strength and temperature, neutron reflectivity measurements were performed.

Low-energy Muon Spectroscopy and magnetisation measurements on high T_c superconductor / ferromagnet multilayers have shown an unexpected increase of the magnetisation below T_c, where the YBCO layers enter the superconducting state. [1]
To obtain more information about the magnetic field profile in the multilayer, non-polarised neutron reflectivity curves have been measured on TOPSI and some polarised measurements were performed on AMOR.
Reflectivity curves of periodic multilayers can roughly be interpreted by the analysis of 3 features: –The critical angle of total reflection ω_c displays the mean scattering length density of the top layer. A change in its magnetisation thus leads to a shift of ω_c. –The decay of $R(\omega)$ for $\omega > \omega_c$ is influenced by the shape-function of the interfaces. In general this means by their roughness. –The periodicity of the interfaces leads to a Bragg condition for constructive interference of the diffracted neutrons. The appearance of these "Bragg peaks" and their intensities allows to deduce the distances between the interfaces and the contrast in scattering length densities of the layers. Besides for the most simple systems this deduction requires model assumptions and simulations.
In Fig. 1 $R(\omega)$ curves are shown for two samples. The upper curves belong to a multilayer with equally thick

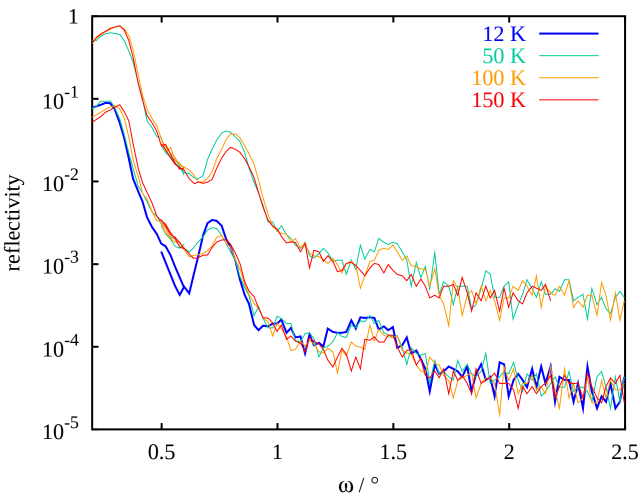

Figure 1: Specular reflectivity of the samples [YBCO(100 Å)/LCMO(100 Å)]$_7$ (×10, *upper curves*) and [YBCO(140 Å)/LCMO(70 Å)]$_7$ (*lower curves*) at several temperatures and in an external magnetic field $H = 100$ Oe. The measurements were performed on TOPSI at $\lambda = 4.74$ Å.

YBCO and LCMO layers. This condition leads to an extinction of the 2nd Bragg peak. Below $T_{\mathrm{Curie}} \approx 170$ K the LCMO layer becomes ferromagnetic and thus the contrast between the layers increases or decreases depending on the neutron spin. As a consequence the 1st Bragg peak intensity increases. At about 130 K also the 2nd Bragg peak appears which is only possible if the magnetic field profile does no longer match the nuclear one. This effect can be explained by assuming that the magnetic field penetrates some 10 Å into the YBCO layers. This penetration persists below $T_c \approx 70$ K as can be seen in Fig. 2.

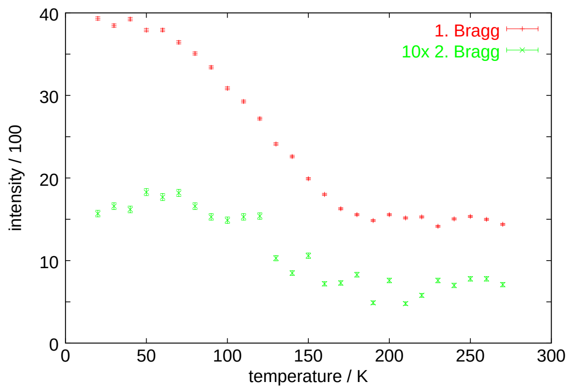

Figure 2: Temperature dependence of the integrated intensities of the 1st (*upper curve*) and 2nd Bragg peak (×10, *lower curve*) of the sample [YBCO(100 Å)/LCMO(100 Å)]$_7$.

For the 2nd sample (lower curves in Fig. 1) the 3rd Bragg peak is forbidden by symmetry. Due to the weak signal and the rather high background it is not possible to detect its appearance for low T. Here an other phenomenon appears: the strong decay of $R(\omega, T = 15\,\mathrm{K})$ just above ω_c indicating a substantial increase in the magnetic roughness. This effect is possibly related to the effects seen by Low-Energy μSR. Here more detailed investigations have to be performed.
An antiferromagnetic coupling of the ferromagnetic layers would lead to a doubled period an thus to additional Bragg peaks. These are not visible in any of our measurements.

[1] C. Bernhard et al., PSI Scientific Report 2002 III, 84
[2] H-U. Habermeier et al., Physica C **364-365**, 298 (2001)

This work was performed at SINQ on the instruments TOPSI and AMOR.