Experiment title:
Magnetic properties of cluster-layered Fe/Cr multilayers revealing Kondo-like behavior of resistivity

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MA-2391

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ID18

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Report:

The basic task of our proposal was the link of the observed Kondo-like behavior of the cluster-layered [Fe/Cr] multilayers to their magnetic and structural properties.

We have investigated four samples $Al_2O_3/Cr(70Å)/[^{57}Fe(1.2Å)/Cr(10.5Å)]_{30}/Cr12Å$ (**A1**), $Al_2O_3/Cr(70Å)/[^{57}Fe(2.1Å)/Cr(10.5Å)]_{30}/Cr(12Å)$ (**A2**), $Al_2O_3/Cr(70Å)/[^{57}Fe(8Å)/Cr(10.5Å)]_{30}/Cr(12Å)$ (**A3**) and $Al_2O_3/Cr(70Å)/[^{57}Fe(8Å)/Cr(20Å)]_{30}/Cr(12Å)$ (**F2**).

The first two samples (A1 and A2) have shown the very pronounced Kondo-like behavior (Fig. 1 - measurements in the IMP RAN) but we have not observed any evidence of the periodic structure due to the very thin ^{57}Fe layers. Therefore, these samples were studied by measurements of the Mössbauer spectra of reflectivity near the angle of the total external reflection (for A1 see Fig. 2).

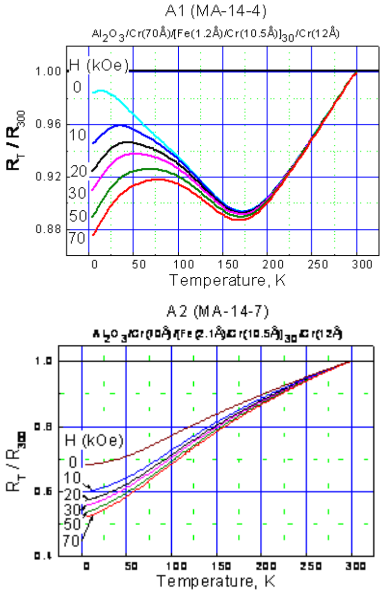

Fig. 1. Results of the resistance measurements.

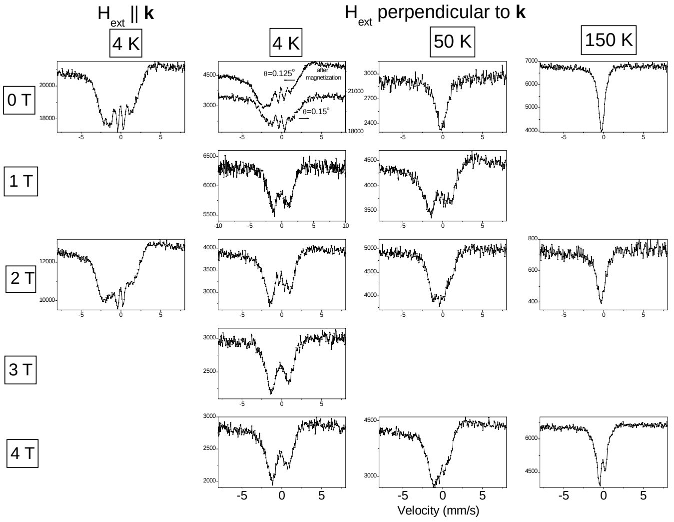

Fig. 2. Mössbauer spectra of reflectivity measured at the set of temperatures and external fields applied parallell and perpendicular to the beam in the surface palne.

The comparison of Figs.1-2 allows us to see the connection between the magnetic state establishing in our films and the Kondo behavior. Rise of resistance at low temperature corresponds to appearance of the magnetic ordering. Since the incident beam is polarized the shape of the Mössbauer spectra strongly depends on the hyperfine field (B_{hf}) direction. In the strong enough external field if B_{hf} aligns perpendicular to the beam we see just the 2 and 5th lines (they could me mixed with the doublet at first sight), but if B_{hf} aligns along the beam the other 1,3,4 and 6 lines appear, confirming the magnetic ordering. However, the quantitative description needs more detailed measurements.

The sample A3 has shown the typical behavior, characteristic for a multilayer with antiferromagnetic interlayer coupling. We have seen the “magnetic” maximum on the nuclear reflectivity curve which at first in the increasing field enlarges slightly as the field is applied perpendicular to the beam and disappears at ~ 3 T for both field orientations. The nuclear reflectivity curves were measured with synchrotron Mössbauer source by the automatic integration over the energy scale in the limits of the Doppler vibrator (we have checked the intervals ~ $\pm$ 12 mm/s, $\pm$ 5 mm/s and at last choose $\pm$ 10 mm/s). The Mössbauer spectra confirm that at the relatively low external field the antiferromagnetically coupled magnetic moments rotate to the perpendicular orientation to the field direction (i.e. orient along the beam) but at the strong field go to the ferromagnetic alignment along the external field (only 2 and 5th lines are seen for the perpendicular field orientation).

The most interesting case we have with the sample F2 which supposed to have the ferromagnetically coupled ^{57}Fe layers (because the spacer Cr thickness is nominally 2 nm). However, we immediately have seen the “magnetic” maximum on the nuclear reflectivity curve. With field applied perpendicular to the beam (Fig. 3) the “magnetic” maximum almost completely disappeared at ~1 T (compare with the sample A3 in which this maximum disappeard at much more strong field, namely at 4 T). So small value of the saturation field in addition with the existance of the 2 and 5th lines in Mössbauer spatrum measured at the “magnetic” maximum (which should be absent in the case of pure antiferromagnetic allignment) - see inserts in Fig. 3 – suggest that in this case we have the nonclollinear magnetic structure.

The additional feature observed near the 1st order Bragg peak on the nuclear reflectivity curve, measured at zero external field (Fig. 4), could be also explained by this suggestion (like it was observed for PNR in the article of S.G. E. teVelthuis et al. [PRL **89**, 127203 (2002)]).

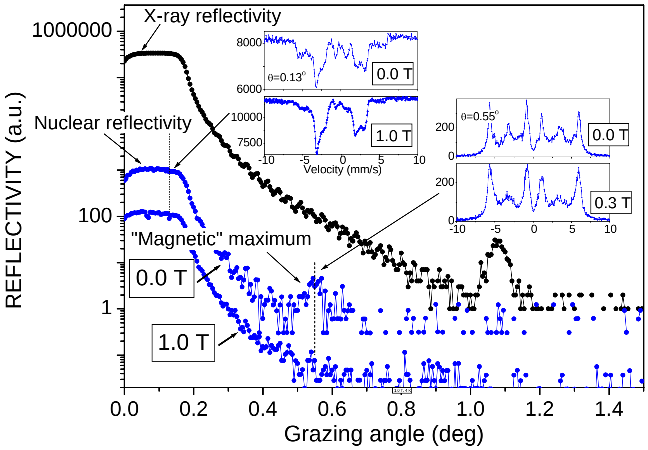

Fig. 3

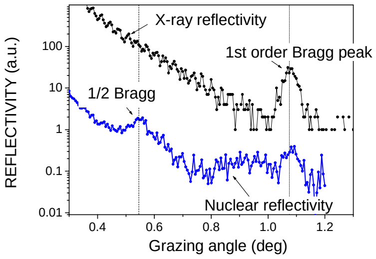

Fig. 4.

However, the observed distorsion of the 1st order Bragg peak (Fig. 4) could as well be the consequence of the difuse scattering on magnetic domains. These issues should be clarified in further investigation of this sample.

In summary:

The performed experiment has shown the great advantages and very high informativity of the new set-up installed at ID18, namely the efficiency of the synchrotron Mössbauer source.

The relation between Kondo-like behavior and magnetic phase transition in [Fe/Cr] multilayers with the extremely thin ^{57}Fe layers (~0.1 nm) has been established by the measurements of the Mössbauer spectra of reflectivity near the critical angle of the total reflection.

The variations of the magnetic hyperfine field alignments in different layers have been observed under the application of the external field by the “magnetic” maximum intensity decreasing and by the redistribution between different lines in Mössbauer spectra.

The unexpected noncolllinear interlayer coupling between ^{57}Fe layers is suggested for the sample with relatively large thickness of the Cr spacer layer (~2 nm) and should be investigated more thoroughly.