ESRF	**Experiment title:** Temperature and field dependent magnetic ordering in [Fe/ Cr]*n superlattices revealing Kondo-like behavior of resistivity	**Experiment number**: MA-4429
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Shifts: 18	**Local contact(s)**: Dr. Aleksander Chumakov	*Received at ESRF:*

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Report:

The goal of our experiment was (a) to link Kondo-like behavior (anomalous increasing of electrical resistivity at low temperatures) of the cluster-layered $[Fe/Cr]_{30}$ multilayers to their magnetic properties and (b) to improve resolution of Mössbauer spectra by applying polarization analysis of reflected beam. For this purpose we have 3 samples with Kondo-like effect ($[^{57}Fe(0.8\ Å)/Cr(10.5\ Å)]_{30}$, $[^{57}Fe(1.2\ Å)/Cr(10.5\ Å)]_{30}$, $[^{57}Fe(2.1\ Å)/Cr(10.5\ Å)]_{30}$.) and 1 multilayer sample $[^{57}Fe_{10}/V_{10}]_{20}$

First measurements show that the best sample for the project was $[^{57}Fe(0.8\ Å)/Cr(10.5\ Å)]_{30}$ and we focused on it. We did not expect any evidence of the periodic structure due to the very thin ^{57}Fe layers. Therefore, this sample were studied by measurements of the Mössbauer reflectivity spectra near the angle of the total external reflection. The sample was nonmagnetic at room temperature so the measurements was performed at low temperatures: 4, 25 and 50 K (Fig. 1.). The spectra changes indicate magnetic transition between ferromagnetic alignment (at 4 K) and superparamagnetic state (at 25K). Field dependence of the Mössbauer spectra at 25K shows stabilization of superparamagnetic phase induced by external magnetic field. While at 4 K the spectra shows spin reorientation caused by external field.

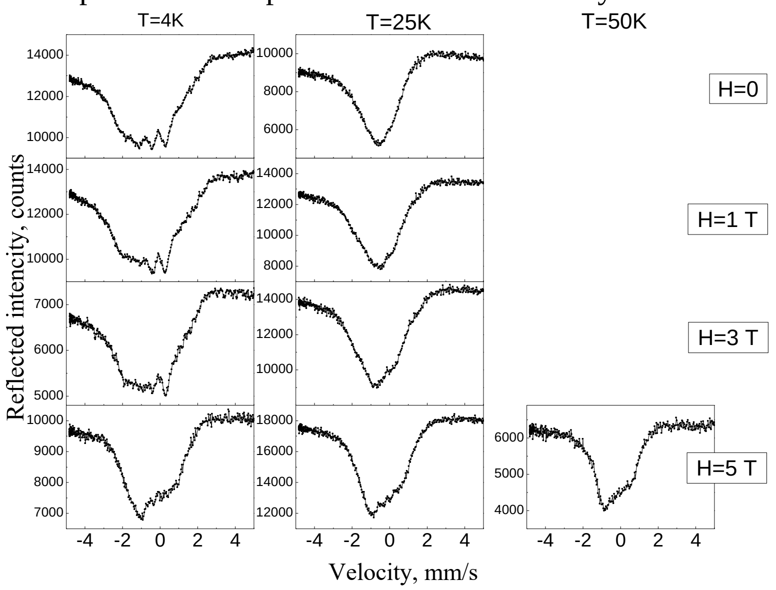

Fig. 1. Mössbauer reflectivity spectra measured at the set of temperatures and external fields applied parallel to the beam .

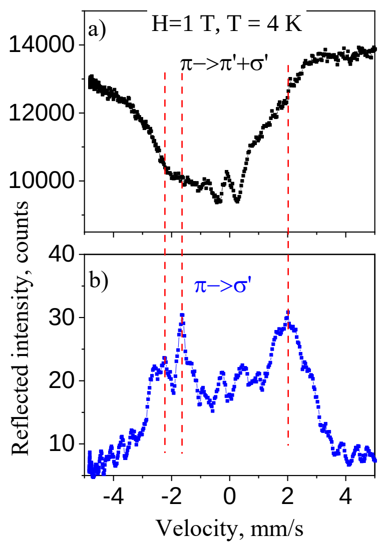

Fig. 2. π→ π+σ` and π→σ` Mössbauer reflectivity spectra at 4K, 1 T

To improve the resolution of poorly resolved Mössbauer spectra (which are typical for structures with ultrathin Fe layers (~0.1 nm)) we have used polarization analyze of reflected beam. For polarization analysis we used LiF (622) crystal which was tested at our previous experiment MA-4040.We record $\pi \rightarrow \sigma`$ Nuclear resonant reflectivity (NRR) near critical angle. At maximum of $\pi \rightarrow \sigma`$ signal we measured Mössbauer spectra at 1 and at 5 T with polarization selection. We observed that practically indistinguishable resonant lines at spectrum without polarization selection could clearly seen at $\pi \rightarrow \sigma`$ spectrum. Unfortunately, we have not seen any $\pi \rightarrow \sigma`$ signal at 25 and 50 K. The origin of this effect now is in discussion.

As we significantly speed up data collection of Mössbauer spectra with polarization selection we were able to measure periodically $[^{57}Fe_{10}/V_{10}]_{20}$ with ferromagnetic interlayer coupling.

The impressive difference between Mössbauer reflectivity spectra measured at 1 T near the critical angle without and with polarization selection takes place (Fig. 4 (a) and (b)). It is not only the shape difference (peaks or dips), these spectra differ by contributions. At Mösssbauer spectra without polarization analysis it is clearly seen the additional sextet corresponding $B_{hf} \approx 46$ T which does not contribute to $\pi \rightarrow \sigma`$ spectrum. Also there is no evidence of this sextet at 1st Bragg reflection. This means that there is an additional phase at the surface layers which is not aligned along the field (for example antiferromagnetic oxide) [1].

X-ray reflectivity shows that 2nd Bragg reflection is practically forbidden for electronic scattering (as the thickness of V an Fe layers are practically equal), however, for nuclear resonant scattering (measured as an integral over Mössbauer spectrum) this reflection is allowed (Fig. 3.).

The shape of Mössbauer spectrum measured at 2nd Bragg peak confirms that this reflection has pure nuclear origin and electronic scattering is fully suppressed. We measured a set of spectra at critical angle 1st Bragg and 2nd Bragg at different magnetic fields (H=0, 0.01, 0.02, 0.04, 0.06, 0.1, 1T). We hope that obtained data will allow to extract of magnetization separately for surface layer, periodic part and Fe-V interface regions.

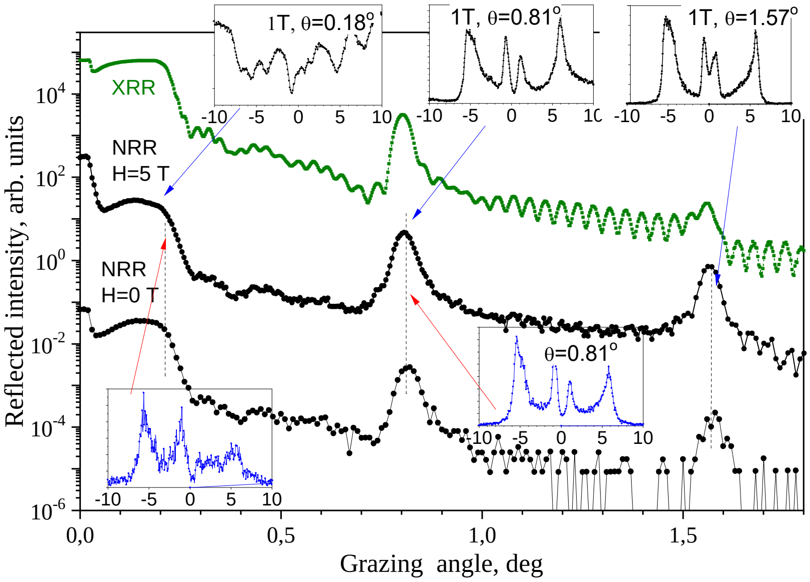

Fig 3. X-ray and NRR curves for $[^{57}Fe_{10}/V_{10}]_{20}$ sample. Mössbauer reflectivity spectra measured at the critical angle and at the 1st and 2nd order Bragg angle without polarization analysis (upper ones) and with $\pi \rightarrow \sigma`$ polarization selection (at the bottom).

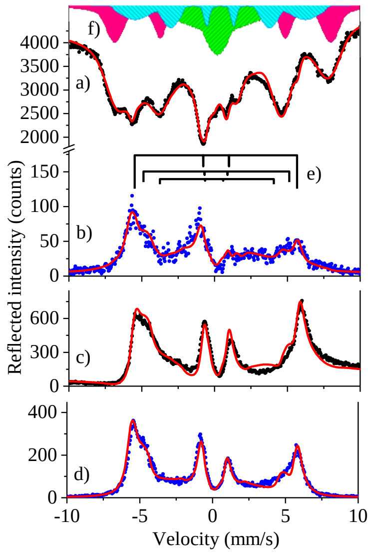

Fig 4.Mössbauer reflectivity spectra measured at the critical angle ((a) and (b)) and at the 1st Bragg ((c) and (d)). The spectra in (a) and (c) were measured without polarization analysis, in (b) and (d) were measured with $\pi \rightarrow \sigma`$ polarization selection. Spectra were mesured at 1 T, 4 K.

Summary

We have significantly improved resolution of poorly resolved Mössbauer spectra by applying polarization analyze of reflected beam. We observed that practically indistinguishable resonant lines at spectrum without polarization selection could clearly seen at $\pi \rightarrow \sigma`$ spectrum.

Field-temperature dependence was measured for sample with Kondo-like behavior. Magnetic transition between ferromagnetic alignment (at 4 K) and superparamagnetic state (at 25K) was observed.

We discovered that polarization selection of reflected beam could be useful for selection ferromagnetic and antiferromagnetic phases.

Finally, we observed pure nuclear Bragg reflection from superlattice on NRR curve which is forbidden for electronic scattering.

Publication

[1]M A Andreeva, R.A. Baulin, O. V. Slinko, et al 2019 J. Phys.: Conf. Ser. 1389 012016.