ROBL-CRG	**Experiment title:** **X-ray reflectivity of Fe/Cr multilayers grown by MBE on Al_2O_3**	**Experiment number**: 20_02_IH4
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Report:
GMR and magnetic behaviour of Fe/Cr multilayers (MLs) depends strongly not only on the layer thickness relations but also on the Fe/Cr interface structure [1- 2]. The aim of the experiment was to use the advantages of the anomalous X-ray scattering for the study of roughness and their morphology of the Fe and Cr layers because the compositional properties of the transition region play important parts in forming ML properties. Therefore specular and off-specular diffuse scans were taken at the energy near the absorption K-edge of Fe (E=7.111 keV) as well as of Cr (E=5.989 keV).
Out of a MBE grown series with varied Fe-layer thickness and Cr buffer layer of 7 nm, a ML (sample UU-9-8) of the composition Al_2O_3/Cr(7nm)/16x[^{57}Fe(1.3nm)/Cr(7nm)] was selected for this experiment.

Experimental: For the two selected energies the measurements were done in the reflectometry ROBL standard set-up (incident beam divergence ≈0.006°, angular detector acceptance 0.03°). Different ω scans (rocking scans with detector fixed at $2\theta_f$) and a $(\theta+\Delta\theta)$-2θ offset scan were done besides the θ-2θ specular scans.

Evaluation and Results
From the simulations (RefSim Code of Bruker/AXS) of the specular scans measured at the energy of the Fe K-edge and the Cr K-edge, respectively, we got the values of layer thickness, rms-roughness and density. The simulation parameters are compiled in Table 1. The quality of the fit could be improved by assuming that the Cr top layer is covered by an oxidised overlayer having a reduced electron density and a high roughness. The simulations show that the Fe layer roughness in the stack is just of the extension of layer thickness.
If we use Sinha‘s fractal model of a self-affine interface structure, incorporated in the REFS simulation software package (Bede Scientific)., the simulations of the diffuse (transverse and offset) scans give the lateral roughness correlation length ξ, the roughness exponent h (Hurst parameter),

Fe/Cr multilayer	RefSIM simulations of the measurements at Fe-edge			RefSIM simulations of the measurements at Fe-edge		
layer type	thickness t (nm)	rms σ (nm)	density (g/cm$^{3)}$	thickness (nm)	rms σ (nm)	density (g/cm$^{3)}$
Cr_2O_3	3.26	1.28	4.17	3.13	0.46	4.00
Cr	8.53	0.09	6.49	8.34	0.04	6.98
Fe	0.93	0.17	6.28	1.03	0.07	7.05
Sublayers: 2 Periods: 15						
Cr	8.49	0.44	7.20	8.52	0.25	7.20
Fe	1.07	1.05	7.86	1.05	1.00	7.52
Cr	4.53	0.55	7.20	4.53	0.55	6.20
Al_2O_3		[0]	[3.97]		[0]	[3.97]

Table 1 Compilation of results received by fitting and simulations of specular scans of the Fe/Cr multilayer UU-9-8 using RefSim Code. The values given in [] brackets are not refined.

and the part of the roughness which is vertically correlated C_v in the multilayer. Table 2 contains the obtained parameters

Fe K-edge						
	$2\theta_f$ (deg)	rms σ_{Fe} (nm)	rms σ_{Cr} (nm)	h	corr. length ξ (nm)	C_v (%)
Bragg peak 3thorder	3.24	1.00	0.75	0.35	15	100
Kiess.minimum	2.66	1.00	0.4	0.35	20	0
Cr K-edge						
Bragg peak 3thorder	2.60	1.0	0.7	0.3	25	>50
Kiess.maximum	2.12	1.0	0.7	0.4	17	50-80%
Kiess. minimum	2.39	1.0	0.7	0.3	25	0

Table 2 Compilation of results received from fitting and simulations of specular and non-specular scans of UU-9-8 using REFS code

In the Cr/Fe MLs the rms-roughness of Cr (σ_{Cr} ≈0.7 nm) is smaller than the rms-roughness of Fe (σ_{Fe} ≈1.0 nm). They have an interface structure with a short lateral roughness correlation length ξ ≈ 20±5 nm. With h≈0.35±05 the h parameter indicate that the ‘jaggedness‘ is relatively high. From this the fractal dimension D=3-h of the interface is estimated at about 2.65. In the transverse diffuse scans from the resonance scattering, which is observed if the detector is fixed at Bragg maxima, it is obvious that the Fe-Cr interface roughness is nearly fully correlated. It means that the most of the measured rms roughness comes from the vertically correlated one. However, the longitudinal diffuse scan shows that the total-layer thickness fringes are nearly disappeared at $\Delta\omega$ =0.1°. This means that the roughness correlation through the multilayer - from the substrate to the top layer - is not so high. This is supported from the diffuse transverse scan with detector position fixed at $2\theta_f$ fixed at a Kiessig maximum. With detector position $2\theta_f$ fixed at a Kiessig minimum, the diffuse scattering is mainly received from the surface. In this case no correlated roughness is found.

References

[1] R. Schad et al., Phys. Rev. **B59**, 1242 (1999)
[2] B. Heinrich and J.F. Cohran, Adv. Phys. **42**, 52 (1993)