The Co/Cr(001) interface is by far less well explored as the Fe/Cr(001) interface. This is partly due to its structural complexity as Co and Cr have different lattice symmetries and the lattice mismatch is considerable. Nevertheless it is worth investigating the heteroepitaxial properties and the spin structure at this interface and to compare it with the Fe/Cr interface. The structural characterization was performed with hard x-rays at the HASYLAB, the spin structure at the interfaces was explored with soft x-rays in resonant mode at BESSY II of the HZB. Here we report only the structural part of our investigation.

1 Sample preparation

We have prepared two trilayer $Cr/Co/Cr(001)$ heterostructures via molecular beam epitaxy (MBE) on a MgO(001) single crystal substrate. The layer sequence of the samples is schematically shown in Fig. 1. For good epitaxial layer-by-layer growth an about 60 nm thick Cr(001) buffer layer was deposited on the MgO(001) substrate at a substrate temperature of 450°C. The crystallinity of the Cr buffer layer was significantly improved by post-growth annealing at a temperature of 750°C for 5 min. For the subsequent growth of the Co and Cr layers the substrate temperature was lowered to 300°C as a compromise between good epitaxial growth and suppression of interdiffusion between the layers. The pseudomorphic growth of Co on Cr(001) is rather complex due to the different crystal structures (bcc for Cr and hcp for Co) and the lattice mismatch. The growth properties are detailed in Ref. [1]. In short, the Co growth starts with a (11\textsubscript{2}0) orientation on Cr(001) where the Co[0001] axis is $\parallel$ Cr[110] axis. This results in a pseudomorphic bcc-like growth of Co on Cr with a 45° epitaxy and lattice misfits of 0.07% parallel to Co[0001] and 6.4% parallel to Co[11\overline{2}0]. Because of the two equivalent [110] in-plane axes in Cr(001), different Co(11\overline{2}0) domains form with an angle of 90° with respect to each other [2]. In addition to this a bcc-hcp martensitic transition takes place as a function of Co thickness within a thickness range up to 4.0 nm [2, 1]. The top Cr layer thickness is chosen such that it protects the sample from oxidation. At the Cr surface a stable oxide forms, which does not grow in time. More details are reported in Ref. [3]. The corresponding parameters of the samples are presented in the inset of figure 2. Sample I and II have slightly different Co layer thicknesses. In sample II with thicker Co layer the martensitic transition is more complete.

2 Structural characterization

Layer thicknesses, interface quality, and epitaxial relationship between Co and Cr were investigated via hard x-ray measurements using the beam line W1.1 at HaSyLab with an incident energy of 10.5 keV (0.118 nm). The resulting reflectivity curves are presented in Fig. 2. Fits of these data using the standard modified Parratt formalism reveals that both samples have comparable layer quality, in particular the roughness of the buffer layer is in both cases similar. A splitting of the Co-layer in two parts increases the fit quality due to a better description of the martensitic transition of the Co-layer. The first part of the Co layer mainly describes this transition and the second part represents the relaxed hcp-Co. The final roughness of sample I (Co thickness 7.2 nm) is higher
than of sample II (Co thickness 10.1 nm). This is an indication of a more complete relaxation in the thicker Co layer.

![Sample design for the Cr/Co/Cr trilayer.](image1)

Figure 1: Sample design for the Cr/Co/Cr trilayer.

![Hard X-ray reflectivities of samples I and II.](image2)

Figure 2: Hard X-ray reflectivities of samples I and II. Inset: Layer thickness (t) and interface roughness (r) of the used samples from Parratt fits.

![X-ray scan in the out-of-plane direction parallel to the surface normal and to the [001] direction of MgO for sample I and II; Inset: in-plane epitaxial relations of MgO, Co and Cr in sample II.](image3)

Figure 3: X-ray scan in the out-of-plane direction parallel to the surface normal and to the [001] direction of MgO for sample I and II; Inset: in-plane epitaxial relations of MgO, Co and Cr in sample II.

The crystalline quality of the samples was investigated with out-of-plane Bragg scans parallel to the surface normal (Cr and MgO [001] direction), see Fig. 3. The results indicate an excellent crystal quality by the appearance of the sharp Cr(002) and Co(1120) peaks. Additionally, Laue oscillations are visible on either side of the Cr(002)-peak confirming the high structural order of the buffer layers. The intensity of these peaks is much higher than that of the Co(1120) peaks, which is due to the difference in thickness of the two layers.

Finally we have investigated the in-plane epitaxy of the different layers via surface x-ray scattering techniques at glancing incident and exit angles. Additionally, a line detector oriented parallel to the sample surface simultaneously measures the intensity for different in-plane Bragg peaks when the sample is rotated about its normal. To reveal the epitaxial relation of the layers the intensity distribution as a function of sample orientation is plotted, see inset of Fig. 3. The positions of the MgO(200), Cr(110), and Co(1100) peaks are marked, revealing the expected 45° epitaxial relation between Cr and MgO due to the coexistence of the Cr(110) and the MgO(200) peaks for one sample orientation. The pseudomorphic growth of Co on Cr with the two different Co(210) domains, which form an angle of 90° with respect to each other, is revealed by the eight Co(2101) peaks appearing in the intensity map upon a complete rotation of the sample (inset in Fig. 3).

References