ESRF	**Experiment title:** Origin of the MAE in two-dimensional alloyed nanostructures	**Experiment number:** HE2224
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Report:

The proposed experiment aimed at studying the magnetic behavior of two-dimensional bimetallic nanostructures cross-checking the results on small nanoparticles and monolayer films. The magnetic properties we investigated are the magnetic moment, easy magnetization axis, and magnetic anistropy energy (MAE). Our interest is not only focused on the *in situ* grown structures itself but also on the effect of induced polarization into the substrate for coverages close to 1 ML.

During our beamtime we carried out measurements on the following systems: *i*) single atoms and pure dimers (coverage about 1% of a monolayer (ML)) of Fe an Co deposited on Pt(111) and Rh(111), *ii*) bimetallic particles made up of Fe and Co grown on Pt(111) *iii*) thin films of about 1 ML of Fe respectively 1 ML of Co on Rh(111) and Pt(111).

The measurement suffered from many beam lost events (we couted at least 7) which had a strong negative effect on the study. A quentch of the superconducting magnet caused a loss of one sample meaning 12 h of beamtime. The first two mentioned systems are highly sensitive to the residual gas limiting their life time to four to five hours, making a comparison among samples having a different history complicated. These data have to be analyzed very carefully and we are not yet at a point to draw a conclusion. The third point, however, yields interesting results.

The samples 1.25 ML Co/Rh(111), 0.60, and 0.80 ML Fe/Rh(111) which will be referred as CoRh, 06FeRh, and 08FeRh were grown *in-situ* by molecular beam epitaxy while the sample was held at $10\,K$. The X-ray absorption spectra (XAS) and magnetization curves were obtained at $10\,K$ in a magnetic field of $B = \pm 5\,T$. The magnetic field is collinear with the photon beam and the sample has a rotational degree of freedom relative to the beam. We define $\theta = 0°, 70°$ by the angle included between the incident beam and the surface normal.

Figure 1 shows XMCD spectra (a) and magnetization curves (b) taken at the Co-edge on CoRh. The XMCD for $\theta = 0°$ and $\theta = 70°$ are normalized to the $(\mu_+ - \mu_-)L_3$ intensity to eliminate the dependence of the electron yield on the sample direction. The magnetization curves were adapted to be consistent with L_3 normalized XMCD spectra. We find the easy axis of the Co film to be in plane, while H. Tokano *et al.* observed perpendicular magnetic anisotropy investigating 3.4 Å Co/Rh(111) [1]. By applying the XMCD sum rules on the spectra measured along the easy axis ($\theta = 70°$) we calculate $m_L/h_d = 0.13\,\mu_B$ and $(m_S + 7m_T)/h_d = 0.70\,\mu_B$ where m_L is the orbital magnetic moment, m_S the spin magnetic moment, m_T the magnetic spin dipole moment, and h_d the number of holes in the 3d states. Neglecting the contribution of m_T and taking for $h_d = 2.5$, we find $m_{Co} = (2.08 \pm 0.20)\mu_B$ in good agreement with calculation by S. Dennler *et al.* finding a value $m_{Co} = 1.95\,\mu_B$ [2].

Measurements on the Fe-edge of 08FeRh are reported in figure 2. Here, we deduce an out of plane orientation of the Fe adlayer with a small MAE in comparison to CoRh. Along the easy axis ($\theta = 0°$) we obtain $m_L/h_d = 0.04\,\mu_B$ and $(m_S{+}7m_T)/h_d = 0.74\,\mu_B$. Again neglecting m_T and assuming $h_d = 3.3$ for Fe bulk holes we estimate the total magnetic moment $m_{Fe} = (2.7{\pm}0.3)\mu_B$. The Fe adlayer clearly evidences ferromagnetic behavior in contrast to the very similar system Fe/Ir(111) where an antiferromagnetic order for the Fe monolayer is found [3].

To investigate the induced polarization in the substrate we measured the XAS at the Rh $M_{3,2}$-edge across the magnetic adlayer. We took special care to average over a larger number of absorption spectra to improve the signal to noise ratio. For both samples we can clearly prove a polarization of the Rh(111) substrate. The XAS normalized to the M_3 pre-edge and offset for clarity are shown in the upper part of figure 3 and 4 for CoRh and 06FeRh, respectively. The resulting XMCD spectra are shown underneath with a 25× magnification, evidencing a larger signal for $\theta = 70°$. In case of 06FeRh the dichroic signal is sensibly smaller compared to CoRh.

Interpretation of the Rh spectra regarding magnetic moment and easy axis are not trivial since we have to deal with an interface effect, i.e. the magnetic moment induced in Rh(111) by the magnetic adlayer is largest at the interface but decays within very few atomic layers. Thus, the measured XAS are a superposition of the topmost polarized layers and non polarized bulk. Moreover the proportion of the polarized versus non-polarized Rh layers to the total signal changes with the angle of incidence masking the identification of the easy axis.

In conclusion, we have characterized the magnetic moment and easy axis of Co and Fe adlayers on Rh(111) and we have supplied evidence of the induced polarization in Rh(111).

References

[1] H. Tokano *et al.*, J. Appl. Phys. **97**, 016103 (2005)
[2] S. Dennler *et al.*, Phys. Rev. B **71**, 094433 (2005)
[3] K. von Bergman *et al.*, Phys. Rev. Lett. **96**, 167203 (2006)

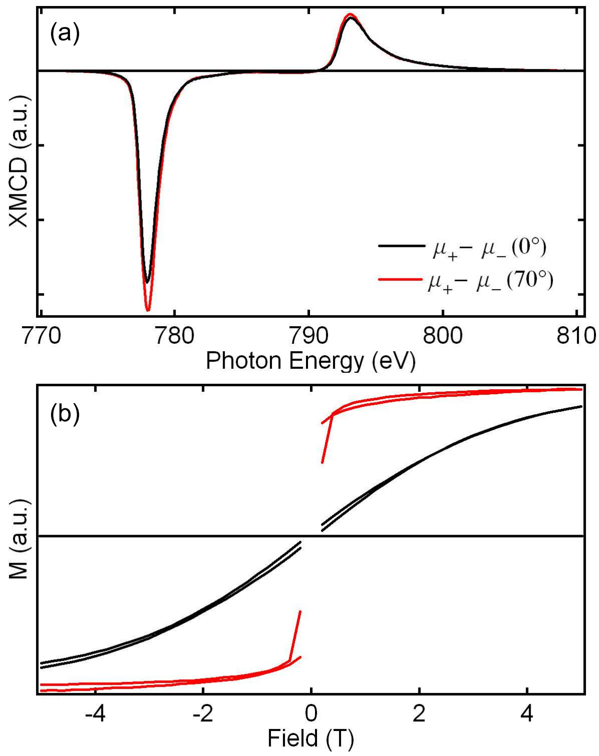

Figure 1: 1.25 ML Co/Rh(111) (a) XMCD for $\theta = 0°$ and $\theta = 70°$ obtained by substraction of the absorption spectra and normalization to the $(\mu_+ - \mu_-)L_3$ intensity. (b) Magnetization curves at $\theta = 0°$ (black line) and $\theta = 70°$ (red line) measured as the ratio of the L_3 XMCD and the pre-edge intensity.

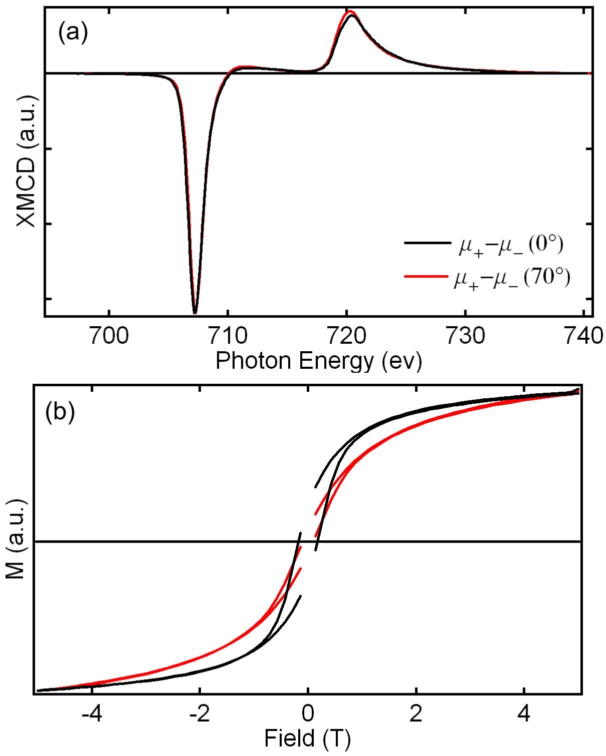

Figure 2: 0.8 ML Fe/Rh(111) (a) XMCD signal for $\theta = 0°$ and $\theta = 70°$ obtained by substraction of the absorption spectra. and normalization to the $(\mu_+ - \mu_-)L_3$ intensity. (b) Magnetization curves at $\theta = 0°$ (black line) and $\theta = 70°$ (red line) measured as the ratio of the L_3 XMCD and the pre-edge intensity.

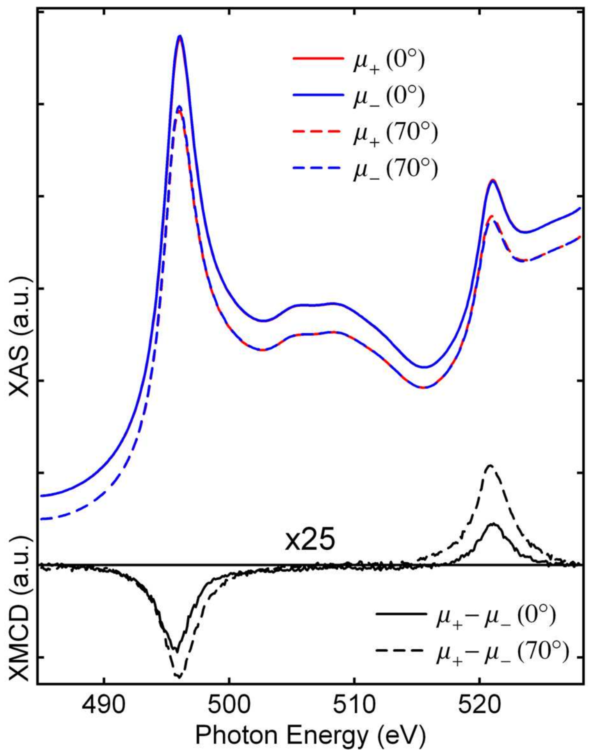

Figure 3: upper part: XAS recorded at the Rh $M_{3,2}$ -edge across 1.25 ML Co for $\theta = 0°$ and $\theta = 70°$. The spectra are normalized to the pre-edge intensity and offset for clarity. lower part: corresponding XMCD obtained by substraction of the absorption spectra.

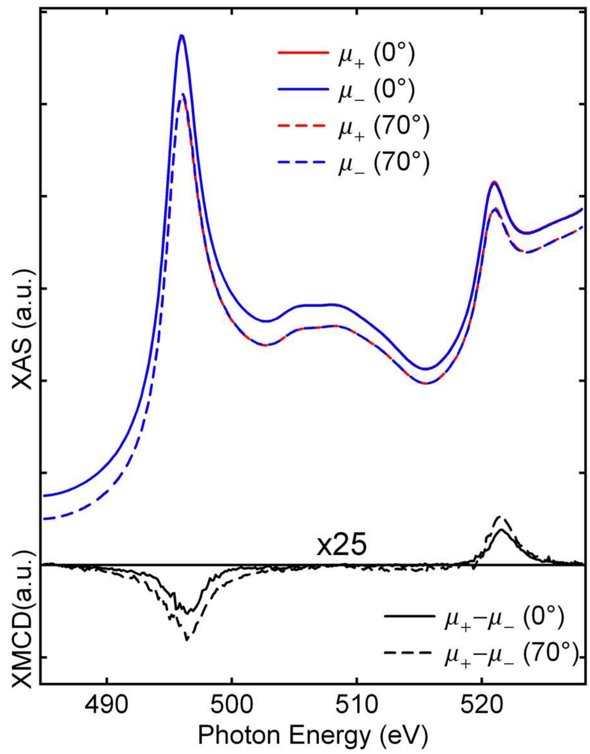

Figure 4: upper part: XAS recorded at the Rh $M_{3,2}$ -edge across 0.60 ML Fe for $\theta = 0°$ and $\theta = 70°$. The spectra are normalized to the pre-edge intensity and offset for clarity. lower part: corresponding XMCD obtained by substraction of the absorption spectra.