ESRF	**Experiment title:** Probing the magnetocrystalline anisotropy in uniaxial systems using x-ray magnetic linear and circular dichroism	**Experiment number**: HE766
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Report:

The origin of the magnetocrystalline anisotropy (MCA) is known to lie in the spin-orbit interaction, but the precise relation between these two quantities has never been determined. In many cases the MCA has been related to the orbital magnetization using Bruno's perturbation model with the assumption of a particular electronic structure [1]. However, it has been shown that the MCA has a much more complicated relation with the orbital magnetisation and that, even with known material dependent prefactors, Bruno's model is not entirely satisfactory [2]. Further, the orbital magnetisation is often determined using x-ray magnetic circular dichroism (XMCD) which introduces additional errors if holes exist in the majority bands. Recently it has been proposed that the microscopic origin of the MCA in 3*d* transition metals is directly related to the anisotropic part of the spin-orbit interaction [3]. In this case x-ray magnetic linear dichroism (XMLD) would be an ideal tool for directly determing the MCA in an element-specific manner.

Here we show that XMLD is a powerful technique with which to determine the spin-orbit anisotropy and relate it to the MCA using a new sum rule. The uniaxial magnetic anisotropy (UMA) for vicinal Co surfaces, determined using XMLD, is shown to vary linearly with the step density and therefore also unambiguously shows that UMA originates from MCA effects as opposed to magnetoelastic contributions.

The Cu(001) and four vicinal surfaces (miscut angles of 1,2,3 and 4º from [001]) were prepared on the same single crystal and cleaned *in situ* using repeated cycles of Ar^+ ion bombardment followed by annealing to 700K. The Co and Fe films were grown by molecular beam epitaxy at temperatures of 300 K; the films were not annealed to avoid interdiffusion and the pressure rise during each deposition was $< 1 \times 10^{-10}$ mbar. By evaporating on a single Cu crystal with 5 surfaces it was possible to ensure that all surfaces had the same film thickness. A pulsed electromagnet was used to align the spin moments parallel to the easy axis of the Co films, but perpendicular to the electric light vector (**E**) of the linear polarised light. In order to align the spin moments perpendicular to the easy axis, and parallel to **E**, a supeconducting 7T magnet was used. To ensure that the TEY measurements were not affected by the magnetic fields, fluoresence mesurements were also taken. The XAS spectra were normalized to a constant edge jump to yield information on a per atom basis.

Figure 1 shows XAS spectra recorded for a 6ML Co film grown on Cu(1 1 20) with the sample magnetisation parallel (solid line) and perpendicular (broken line) to the linear polarisation of the incident x-rays. The two peaks arise due to transitions from the spin-orbit split 2*p* core levels to unoccupied 3*d* states. The XMLD (solid circles) has an integrated intensity of zero. The MCA energy is then given by

$$\text{MCA} = 5\,\zeta\,\delta\,n_h / 24\,I_{iso}$$

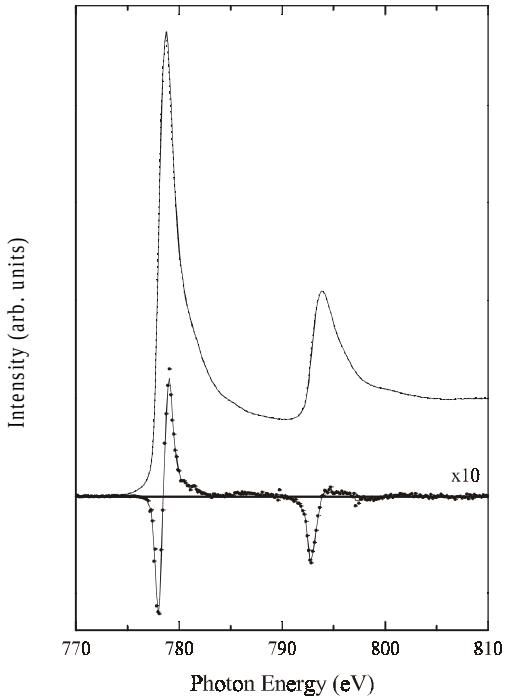

Fig. 1 XAS from a 6ML Co film grown on a Cu surface with a 4º miscut. The resulting XMLD is related to the MCA via a sum rule.

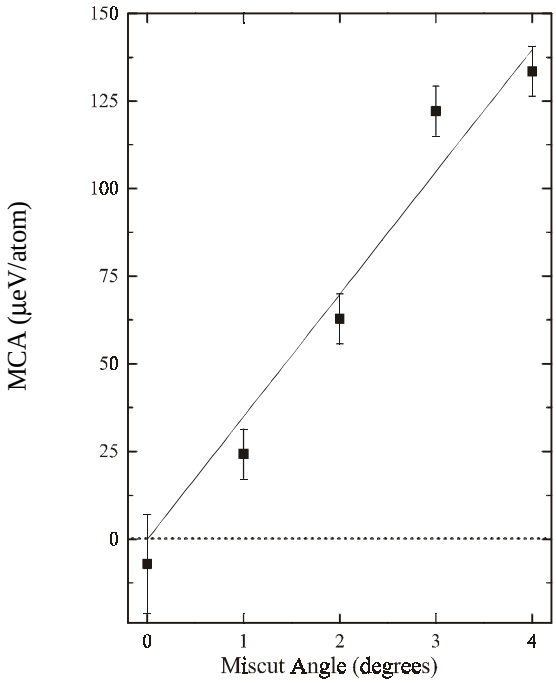

Fig. 2 MCA of a 6ML Co film as a function of step density determined using XMLD.

where n_h is the number of holes in the 3*d* bands, ζ is the spin-orbit constant, I_{iso} is the integrated intensity of the isotropic spectrum [3]. For $2p \rightarrow 3d$ transitons, $\delta = \Delta I_3 - 2\Delta I_2$ where ΔI_3 and ΔI_2 are the integrated intensities over the L_3 and L_2 edges of the XMLD spectrum. The MCA for a 6ML vicinal Co film grown on Cu(1120) is determined to be 133 μeV/atom (ζ = 50 meV; n_h = 2.4) and represents the twofold MCA favouring an easy axis of magnetization parallel to the step edges. The MCA for Co films on all the miscut surfaces is shown in Fig. 2 and clearly exhibits a linear dependence with step density. The linear increase of the UMA with atomic step density agrees with previous magneto-optical Kerr effect studies and excludes biaxial strain as the origin of UMA [4]. Since XMLD measures only the MCA contribution, in the present study we are able to relate the MCA directly to the UMA. Further studies show that Fe overlayers on the Co films exhibit a different MCA to the Co demonstrating the element specific nature of the technique. First principles calculations are presently being performed in order to more fully understand the mechanism of the increase in MCA with step density.

[1] P. Bruno, Phys. Rev B 39, 865 (1989).
[2] A.N. Anisimov et al. Phys. Rev. Lett. **82**, 2390 (1999)
[3] G. van der Laan, Phys. Rev. Lett 82, 640 (1999).
[4] R.K. Kawakami, Phys. rev. B **58**, R5924 (1998).