ESRF	**Experiment title:** Quantum well state induced modulations of the interface magnetocrystalline anisotropy in exchange coupled trilayers	**Experiment number**: HE988
Beamline:	**Date of experiment**: from: 18/06/01 to: 26/06/01	**Date of report**: 28/08/01
Shifts:	**Local contact(s)**: P. Bencok	*Received at ESRF:*

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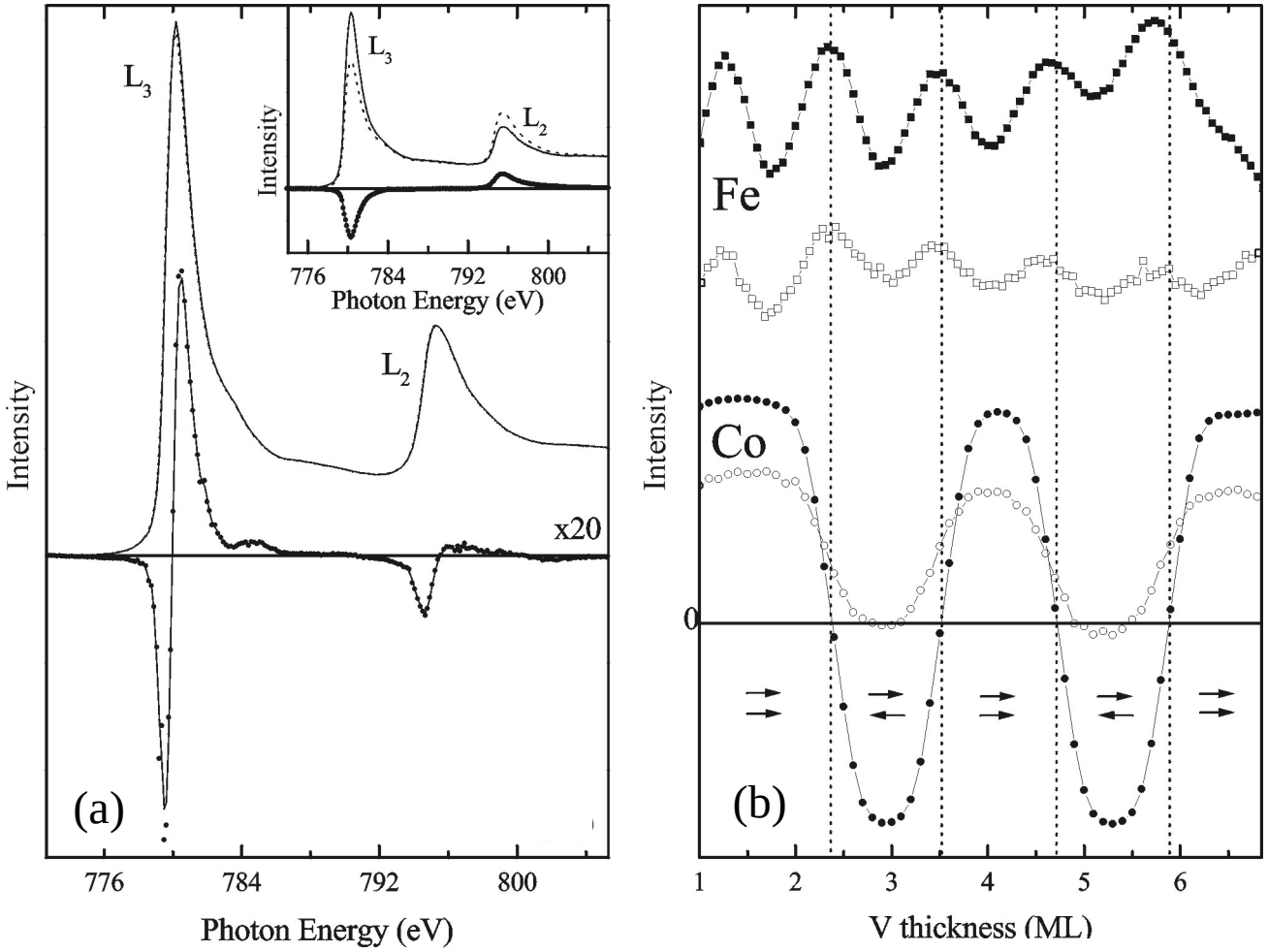
Report:

Recently, *ab initio* calculations have predicted that by tuning the non-magnetic spacer layer thickness, the interlayer exchange coupling (J) can be made to compete with the magnetocrystalline anisotropy (MAE) generating a non-collinear magnetisation profile [1]. For Fe/*n*V/Co (2ML<*n*<12ML) structures, these calculations show that the Fe MAE forces the Fe magnetisation in-plane while the Co moments exhibit an out-of-plane MAE. The competition between J and the Co MAE produces a damped out-of plane to in-plane sinusoidal-like Co magnetisation profile as the V spacer layer thickness is increased. In the absence of MAE contributions the trilayer simply oscillates between ferro- and antiferromagnetic coupling with increasing V thickness. In the present study we used x-ray abosrption spectroscopy (XAS) combined with linear and circular polarized light in order to more fully understand the role of MAE in Fe/*n*V/Co trilayers.

The trilayers were prepared on a well-ordered V(001) surface which was cleaned using well-established procedures. After the deposition of 3ML of Fe onto the V(001) surface, a 1-7ML wedge of V was grown followed by 3ML of Co (see Fig 1(c)). X-ray magnetic linear dichroism (XMLD) has recently been established as an element specific probe of the MAE whereas x-ray magnetic circular dichroism (XMCD) yields the spin , **S**, and orbital, **L**, magnetic moments; both techniques yield quantitative values of the MAE, **S** and **L** through sum rule analysis [2-4]. Here we exploit the fact that the magnitude of the XMLD and XMCD is directly related to the size of the MAE and magnetization (**M**), respectively. Fig. 1(a) shows Co XAS spectra recorded from 3ML Co / 2ML V / 3ML with the electric light vector, **E**, parallel and at 45° to the surface; the difference between the two spectra, *i.e.* the XMLD, is also shown (closed circles). The inset shows XAS spectra for the same sample recorded with the circular polarization vector of the light, **P**, parallel and antiparallel to **M**; the difference between the two spectra, *i.e.* the XMCD, is also shown (closed circles). Similar XMLD and XMCD spectra were also recorded for the Fe $L_{2,3}$ edges. Fig. 1(b) shows Co and Fe XMLD and XMCD for different V spacer thicknesses between the Co and Fe thin films recorded at an angle of incidence of 45°. The spectra in Fig. 1 (b) were recorded by tuning the energy to the maximum of the Co or Fe dichroism and scanning the x-ray beam across the wedge structure; it should be noted that the Fe spectra have been corrected for the varying absorption of the V wedge.

In the present case we first note that the Fe XMCD is always positive. The changing sign of the Co XMCD (Fig. 1(b) closed circles) then reveals the period of the ferro- and antiferromagnetic coupling between the Fe and Co. If the same spectra are recorded at normal incidence all XMLD and XMCD vanishes indicating that the proposed non-colllinear magnetic structure of Ref. 1 has not been observed. This might be ascribed to interface roughness or the magnetostatic anisotropy. However, the Co XMLD (Fig. 1(b) open circles) also oscillates with the same peiod as the Co XMCD showing that the Co MAE is not constant and even goes to

zero for the case of antiferromagnetic coupling between the Fe and Co. We wish to note that although **E** was rotated in this work instead of **M**, the magnetic origin of the XMLD was extensively verified. The fact that the period of the MAE modulation follows the interlayer exchange coupling suggests that the quantum well states are indeed affecting the MAE as conjectured in the original proposal. Interestingly, the Fe XMCD (Fig. 1(b) closed squares) and XMLD (Fig. 1(b) open squares) oscillate with half the period of the Co modulations. It should be noted that only the magnitude of the Fe XMLD and XMCD change (not the sign) implying that the Fe interface MAE and **M** are modulated. The halving of the Fe period is most likely due to quantum well interference originating from the different interfaces. A more quantitative treatment of the data is currently under way.



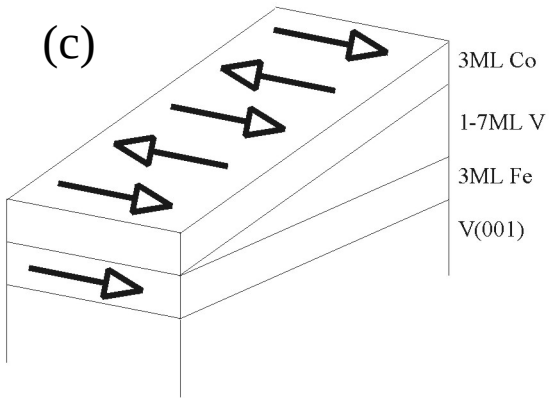


Figure 1 (a) XAS spectra over the Co $L_{2,3}$ edges recorded from 3ML Co/2ML V/ 3ML Fe with **E** parallel (dashed line) and at 45° (solid line) to the surface; the XMLD is also shown (closed circles) The inset shows Co XAS spectra for the same region of the wedge structure with **M** parallel (dashed line) and antiparallel(solid line) to **P**; the XMCD is also shown (closed circles) . (b) The variation in the Co XMCD (closed circles), Co XMLD(open circles), Fe XMCD (closed squares) and Fe XMLD (open squares) with V spacer film thickness. The arrows indicate the coupling between the Fe and Co for different V thicknesses. (c) Schematic representation of the Fe/V/Co trilayer indicating the coupling as determined using XMCD (see Fig. b)

References

[1] A. Taga *et al*., Nature **406**, 280 (2000).

[2] T. Thole *et al*., Phys. Rev. Lett. **68**, 1943 (1992); P. Carra *et al*., Phys. Rev. Lett. **69**, 2307 (1993).

[3] G. van der Lann, Phys. Rev. Lett. **82**, 640 (1999); S.S.Dhesi *et al*., Phys. Rev. Lett. **87**, 067201 (2001).

[4] S.S.Dhesi *et al*., Appl. Phys. Lett. **80**, 1613 (2002).