ESRF	**Experiment title:** Magnetic microstructure in Co-based thin film systems	**Experiment number:** HE-244
Beamline: ID12B	**Date of experiment:** from: 18-Oct-97 to: 26-Oct-97	**Date of report:** 23-Feb-97
Shifts: 21	**Local contact(s):** Dr. M. Finazzi	*Received at ESRF:* - 3 MAR. 1998

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Report:

We investigated magnetic coupling phenomena in ultrathin film systems using a dedicated photoelectron emission microscope and exploiting the soft X-ray magnetic circular dichroism at the $L_{2,3}$ absorption edges. Two types of film systems were of particular interest: *(i)* Co/Cr/Fe(100), and *(ii)* Co/Ni/Cu(100). In the first system, the Cr film was grown with a defined thickness gradient (wedge) in order to be able to characterize the interlayer coupling between Fe and Co as a function of thickness. Because of the information depth and the element specificity of our experimental approach, we can determine the magnetic behavior of each component (Fe, Cr, Co) in the sandwich. In Fig. 1 we see the domain pattern in the Fe substrate (consisting of two oppositely magnetized domains) and the Co overlayer. The domain structure in the Co layer is typical for an oscillatory interlayer coupling in the system, with a change from ferro- to antiferromagnetic coupling at a Cr layer thickness of about 2 monolayers (ML). This coupling has not been observed in previous experiments [l]. It is attributed to an improved interface quality of the films achieved by a reduced growth temperature. We note the rather narrow transition region for the coupling character which stands in marked contrast to the extended areas of biquadratic coupling appearing in the Fe/Cr/Fe system. A very surprising finding is the magnetic signal in the Cr layer which essentially follows the Co domain pattern. Even at a Cr thickness of more than 2 ML, a magnetic contrast can be discerned. This suggests that the signal originates mainly from the Cr/Co interface and is due to a small amount of Cr being polarized by the Co overlayer. The decrease of the signal above 2 ML Cr is consistent with a build-up of the intrinsic antiferromagnetic spin structure in Cr. This result illustrates the power of the experimental approach. The information cannot be obtained with any other domain imaging technique.

The second system consisted of a thicker Ni-film (typically 15 ML) grown on Cu(100) and covered by a Co wedge. The magnetization M in the uncovered Ni film points normal to the surface [2] due to a magnetoelastic contribution to the magnetic anisotropy. Co, on the other hand, usually favors an in-plane orientation of M. The competition between these two effects on M should lead to a spin reorientation in the Ni layer at some critical thickness of the Co overlayer. In Fig. 2, we compare the domain patterns in the Ni and the Co film. The Co-free region of the Ni film exhibits small irregular domains indicative of a perpendicular magnetization. This is the first time that a perpendicular magnetization has been successfully imaged with photoemission microscopy. We see that up to 1.5 ML Co the Ni film imposes its magnetization direction on the Co overlayer (I). Above 3 ML Co M lies entirely in the surface plane (||) and the domain pattern is qualitatively different. This is due to the fact that a (001) surface has several in-plane magnetic easy axes, resulting in four possible orientations of the local magnetization and a higher number of grey levels in the images. Between 1.5 and 3 ML we find a transition region where only very few domains at the left-hand boundary can be resolved. The domains on the right-hand side of the transition region are probably too small to be seen with the present resolution of the set-up (150 nm). Within this limit the local magnetization in the Co and Ni film behaves the same in all regions described above, as can be expected from two ferromagnets in direct contact.

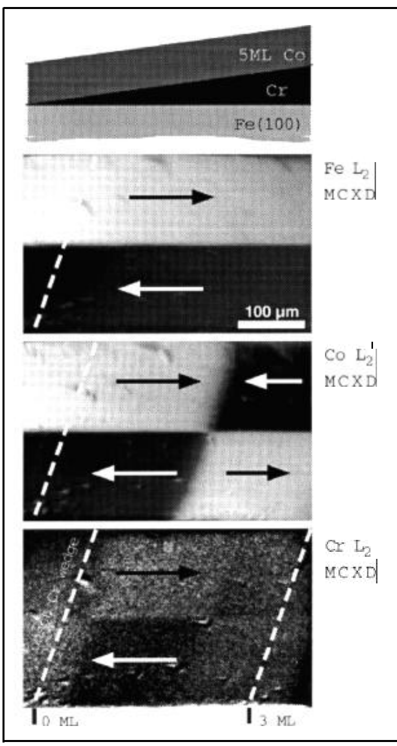

Fig. 1: Element-resolved magnetic domain patterns in an exchange-coupled Co/Cr/Fe(100) sandwich. Arrows indicate the local direction of the magnetization vector.

References:

[I] CM. Schneider, R. Frömter, Ch. Ziethen, W. Swiech, N.B. Rrookes, G. Schönhense, J. Kirschner, Mat. Res. Soc. Symp. Proc. Vol. 475, 381 (1997)

[2] B. Schulz, R. Schwarzwald, and K. Baberschke, Surf. Science 307-309, 1102 (1994).

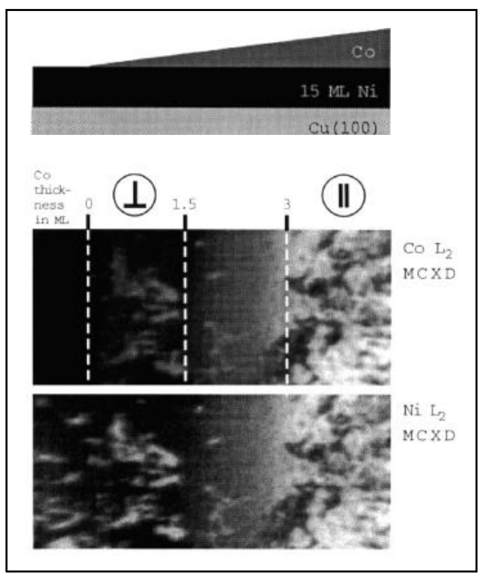

Fig. 2: Element-resolved magnetic domain patterns in an exchange-coupled Co/Ni/Cu(100) sandwich. With increasing Co thickness the magnetization of the whole system flips from normal (I) to the surface to in-plane (||).