ESRF	**Experiment title:** **Direct Observation of Bulk Spin Flop Transition in a Magnetic Superlattice by Synchrotron Mössbauer Reflectometry**	**Experiment number:** SI-508
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Report:

Metallic multilayers built from ferromagnetic layers separated by non-magnetic spacer layers often show antiferromagnetic (AF) interlayer coupling, a well-known example being the Fe/Cr system. Besides their interaction J, the layer magnetisations **M** in a magnetic multilayer (MML) experience the magneto-crystalline anisotropy A. In case of a *fourfold anisotropy symmetry* and with the provision that **M** of each Fe layer is confined to the sample plane, for H_{ext}=0 one has two, mutually perpendicular, initial directions of equal energy of the magnetisation axis. In nonzero external fields one of the anisotropy-stabilised configurations becomes energetically unfavourable and, *at a certain* critical external field depending on the *J/A* ratio, it abruptly moves to a more favourable state. This is an example of the *bulk spin flop* (BSF) transition, a well-known phenomenon in atomic antiferromagnets. Nevertheless, the change of the direction of the layer magnetisation during a BSF transition in *multilayers* has not yet been directly observed.

Important note: In case of a *twofold anisotropy symmetry or uniaxial anisotropy* [e.g. the case of epitaxial MgO(110)Fe/Cr(211) MMLs] one has a single easy axis and depending on the *J/A* ratio a certain *region of external field* exists in which a rich variety of non-collinear MML structures can be observed. As a function of increasing external field, high angle jumps of the sub-layer magnetisations occur while the conventional magnetisation curve remains smooth. This latter state — for a wide range of *J/A and* H_{ext}/A — is restricted to a certain region of the multilayer stack and it is often surface-induced. Therefore this MML state is often called *Surface Spin Flop* (SSF) state. The original proposal was formulated for the observation of the SSF state. However, in spite of our great endeavour and the promising preliminary results, the preparation of the FeCr(211) MML on MgO(110) showing SSF properties as described in the literature was unsuccessful before the scheduled beam time. Therefore the fourfold anisotropy case, BSF transition was experimentally studied on a MgO(001)/[^{57}Fe(25 Å)/Cr(14 Å)]$_{20}$ superlattice in details in this experimental run SI-508.

The experiments were performed in "George" the split-coil multiple-stage superconducting magnet cryostat at ID18. The temperature of the sample stage in the variable temperature unit was kept at 294±2 K. Experiments were performed in the perpendicular field geometry ($\mathbf{H}_{ext}$ perpendicular to the scattering plane). For the in-plane magnetisation cycle of the sample described below, the orientation of the inner cryostat and that of the sample stage was turned relative to each other.

Below the phenomenon of BSF is explained with the help of Fig. 1 showing the low-field results of the experiment on MgO(001)/[^{57}Fe(25 Å)/Cr(14 Å)]$_{20}$. The magnetisation of the individual Fe layers points parallel or antiparallel to either of the Fe[010] or Fe[100] axes in the film plane (cf. the blue double arrows in inset 1 of Fig. 1). First the sample is saturated in plane in one of the easy directions (inset 2) then the external field is decreased to zero (inset 3), then the sample is turned in plane by 90 deg and time integral SMR angular scans are recorded as a function of increasing external magnetic fields (insets 4 and 5) at a grazing angle between 0 and 1 deg. The scattering plane was kept vertical and the wave-vector **k** was kept perpendicular to the in-plane magnetic field. Under such conditions, no AF superreflections can be observed in the time integral scans (if **M** is perpendicular to **k**) but those reflections appear in the **M** parallel to **k** case. The spectra in Figure 1 are a series of time integral scans taken in increasing magnetic fields up to 25 mT. The peaks 0 and 1 are the total reflection peak, and the first order structural Bragg reflection, respectively. The intensity of the structural Bragg peak was used for normalisation of the spectra. The appearance of the 1/2 and 3/2 order AF reflections from 14 mT upwards is a direct evidence of the 90 deg rotation of the Fe layer magnetisations, i.e. evidence of the BSF process. When decreasing the field to zero, the sublayer magnetisations are aligned in the easy direction *perpendicular to* the external field, therefore the AF superreflections do remain at maximum intensity in the time integral scans. Turning the sample in zero field and increasing the field again, it was possible to repeat the BSF-transition.

Implications concerning the domain wall movement in the BSF process and the relation of the spin-flop field to the bi-linear and bi-quadratic coupling as well as that to the anisotropy strengths will be described in the upcoming publication.

Reference

L. Bottyán, J. Dekoster, L. Deák, B. Degroote, E. Kunnen, C. L'abbé, G. Langouche, O. Leupold, M. Major, J. Meersschaut, D.L. Nagy, R. Rüffer, to be published

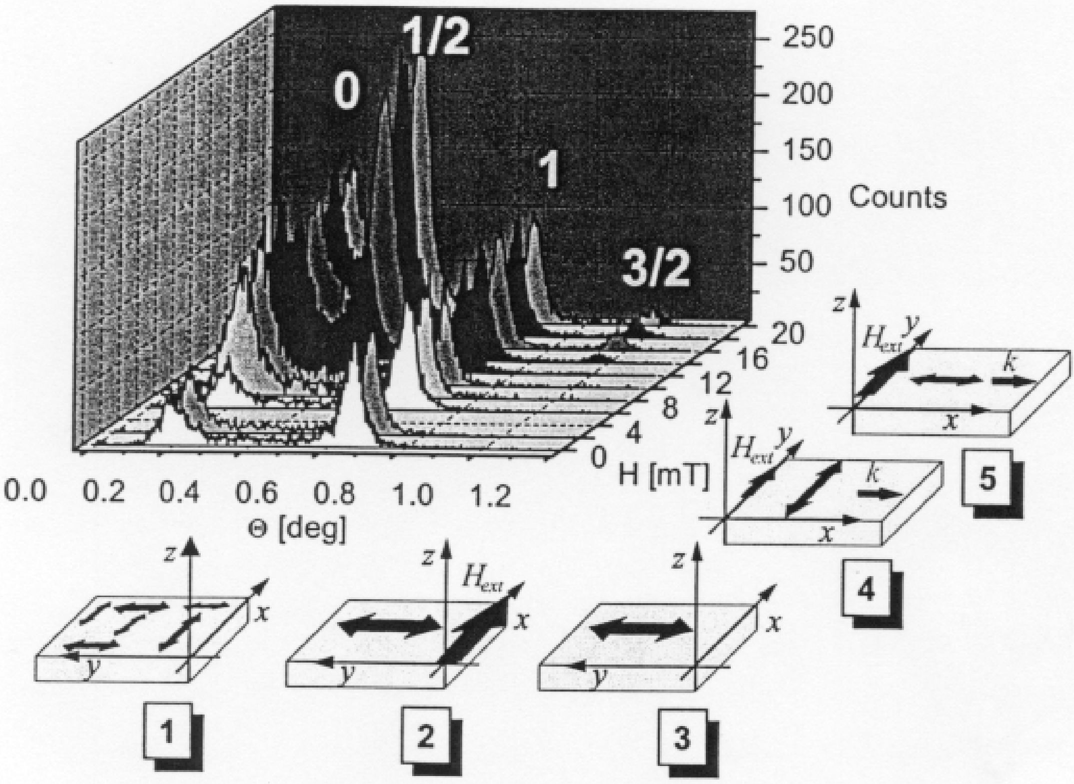

Fig. 1. Time differential SMR curves taken on a MgO(001)/[^{57}Fe(25 Å)/Cr(14 Å)]$_{20}$ superlattice in increasing magnetic field. The appearance of the antiferromagnetic reflections shows the rotation of the layer magnetisations at the bulk spin flop transition. The system of coordinates is fixed to the superlattice.