Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office using the **Electronic Report Submission Application:**

http://193.49.43.2:8080/smis/servlet/UserUtils?start

Reports supporting requests for additional beam time

Reports can now be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** Towards the origin of the trainingeffect in exchange bias: a study of Fe/CoO.	**Experiment number**: HE-2582
Beamline: ID18	**Date of experiment**: from: 7-2-2008 to: 13-2-2008	**Date of report**: 22-3-2008
Shifts: 15	**Local contact(s)**: Dr. Rudolf Rueffer (e-mail: rueffer@esrf.fr)	*Received at ESRF:*

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Report:

The first tentative measurements of the different steps of the magnetization reversal in polycrystalline Fe (ferromagnet) / CoO (antiferromagnet) exchange bias thin film systems were performed. This Fe/CoO system shows a large horizontal shift of the hysteresis loop, known as the exchange bias effect, when it is cooled in the presence of a magnetic field to low temperatures (< 20 K). Besides the horizontal shift of the hysteresis loop, thepolycrystalline Fe/CoO system also shows a pronounced training effect and asymmetry at low temperatures (< 20 K) [1]. The training effect implies that the shift of the hysteresis loop for the second and all consecutive hysteresis loops is smaller than for the first hysteresis loop measured right after field cooling. The asymmetry refers to the fact that the left hand side branch of a Fe/CoO hysteresis loop is much sharper than the more slanted right-hand side branch. The asymmetry is only present in the first hysteresis loop right after field cooling. The training effect and asymmetry are two phenomena that have their physical origin in the domain structure of the antiferromagnetic layer. After field cooling, the antiferromagnetic uncompensated spins are oriented along the cooling field direction, but during the very first reversal, the uncompensated spins are fragmented into different directions. Once this fragmentation has occurred, it cannot be removed during consecutive loops, even if a very high field pulse (> 35 T) is applied. Since the ferromagnetic layer is exchange coupled to the antiferromagnetic layer, the ferromagnetic layer is expected to be fragmented into small domains at the interface [2,3].

The aim of this study was (a) to measure the depth profile of the magnetic moment in the Fe layer, (b) to prove the fragmentation of the domains at the interface between Fe and CoO and (c) to reconstruct changes of the depth profile as a result of the training effect. The Fe/CoO bilayers were grown by molecular beam epitaxy (MBE) on a thermally oxidized Si wafer with a SiO_2 thickness around 500 nm. During this beam time three samples were measured where the Fe-layers consisted of the Mössbauer-inactive ^{56}Fe isotope and

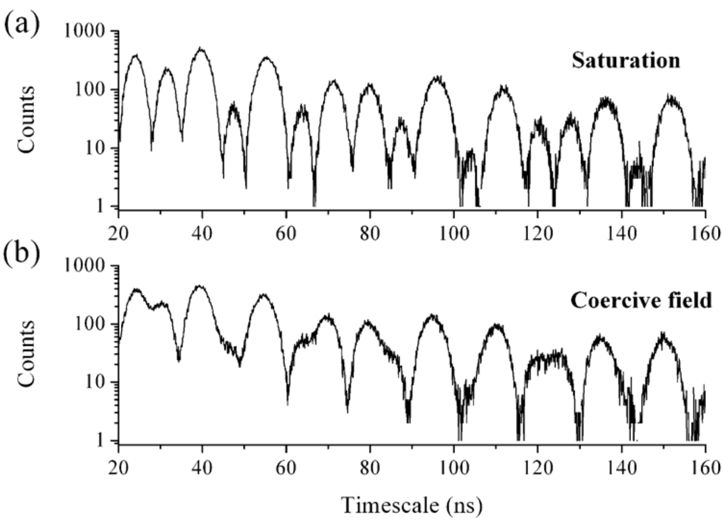

Figure 1 ***Time spectra of nuclear resonant scattering from a Fe/CoO system, with an ^{57}Fe- probe layer at the interface. The beat pattern at saturation (a) and at the first coercive field after field cooling (b) are shown.***

a 2 nm thick ^{57}Fe active probe layer, which was placed at the interface, 3.5 nm away from the interface and at the top of the ^{56}Fe-layer, respectively. The synchrotron radiation excited the hyperfine-split nuclear energy levels of the ^{57}Fe atoms, giving characteristic beats in the temporal evolution of the nuclear decay signal, allowing the determination of the moment rotation in the Fe-layer. The beat patterns were measured at important points along the hysteresis loop for all three samples. Figure 1 shows the beat pattern at saturation (a) and at the first coercive field after field cooling (b) for the sample with the probe layer at the interface. A clear difference between the beat patterns is obtained, which identifies the rotation of the Fe-moment. The aim of the measurements was also to identify a difference between the three samples and thus obtaining a depth profile of the magnetic moment. Since the differences are expected to be small, a very high count rate is necessary. This high count rate was achieved, even for the sample with the probe layer at the interface (800 counts/s). Nevertheless, a change of the depth profile of the magnetic moment and a large horizontal shift of the hysteresis loop was never observed. A preliminary analysis of the spectra using the CONUSS code indicates that during reversal the magnetization rotates over about 50°, then flips over, and then rotates further to the opposite direction. It was finally made clear that the required low film temperature (~10 K) could not be reached, which was confirmed by inelastic measurements (the actual film temperature was about 70 K). The thick SiO_2 layer (500 nm) in combination with a cold finger cryostat prevented us to cool the sample to these low temperatures [4]. The straightforward way to circumvent this problem is by using a suitable substrate, which can be used in combination with a cold finger cryostat.

To conclude, the first tentative study was successful in that respect that it was possible to see a large change between the different time spectra at several places in the hysteresis loop. A fitting procedure can perfectly deduce the direction of the Fe moments in the probing layer. Furthermore, a very high count rate was observed, which makes it possible to identify small changes in the different time spectra and to reconstruct the depth profile of the magnetic Fe moment. A continuation of the measurement is, however, necessary in order to reach the lower temperatures and to understand the training effect and asymmetry in polycrystalline exchange bias systems.

References

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[4] M.B. Kleiner, A. Kühn, and W. Weber, IEEE T. Electron Dev. **43**, 1602 (1996).