ESRF	**Experiment title:** Novel magnetic order in Fe/Fe-oxide superlattices	**Experiment number:** HE 2156
Beamline: ID18	**Date of experiment:** from: 16.05.2006 to: 31.05.2006	**Date of report:** 13.02.2007
Shifts: 45	**Local contact(s):** S. Stankov	*Received at ESRF:*

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Report:

The aim of the experiment was to analyse the magnetic structure in multilayers consisting of iron and its native oxide. To be able to conduct in situ experiments a dedicated transportable UHV chamber has been installed at the beamline. The chamber is equipped with three magnetron sputter sources and an ellipsometer for in-situ and online monitoring of the preparation, which is fully remote controlled. The samples are produced by repeated sputter deposition of a thin iron layers followed by an exposure to 6500 Langmuir of oxygen. In a previous experiment at the ESRF (SI-1259) we could show that buried native iron oxide layers exhibit magnetic properties and that a non-collinear coupling exist between successive oxide layers. In addition to a systematic analysis of the oxide properties it is very interesting to check which influence these have on the magnetism of the metallic iron layers. For that purpose the ^{57}Fe probe layers have been embedded in the pure iron layers which otherwise consist of ^{56}Fe. In a first step a series of time spectra were taken in-situ to follow the evolution of the magnetic properties from a single iron layer over a Fe/Fe-oxide bilayer to a trilayer (Fe/Fe-oxide/Fe) in an external field of $\vec{B} = 70\,\mathrm{mT}$, as shown in Fig. 1. The recorded beat pattern for the thin iron layer and the bilayer system are characteristic for a parallel alignment of the magnetic moments in the iron layer with the direction of the photon wave vector. Covering the bilayer with another iron layer leads to a significant change in the time spectrum (Fig. 1c). This can be attributed to a non-collinear alignment of the magnetic moments in the two probe layers resulting in a coupling angle of $60° \pm 5°$, which is symmetric about the direction of the external field.

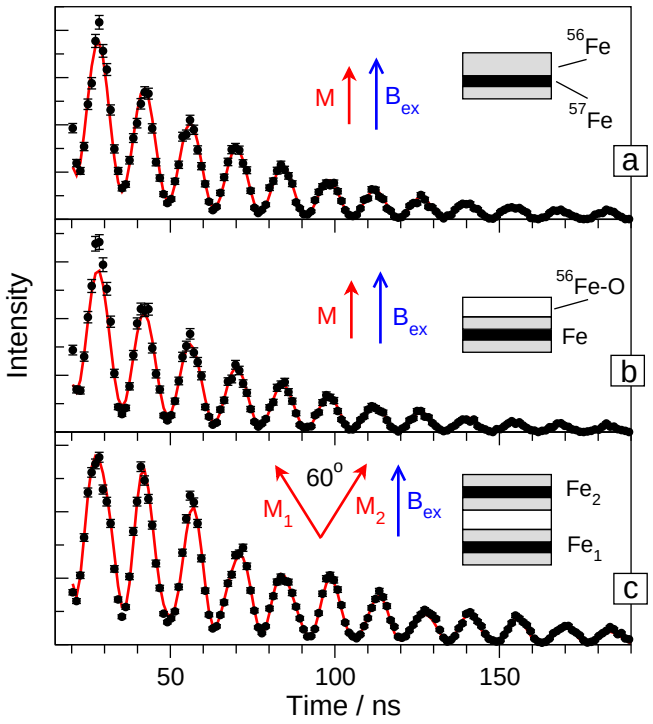

Fig. 1: Time spectra of NRS at different steps of the growth of a Fe/Fe-oxide/Fe trilayer. The solid lines are simulations from which the direction of the magnetic moments relative to the external magnetic field of $\vec{B}$=70 mT was deduced. For a single iron layer the magnetic moment is parallel to $\vec{B}$ whereas the two Fe moments in the trilayer are canted by an angle of about 60°.

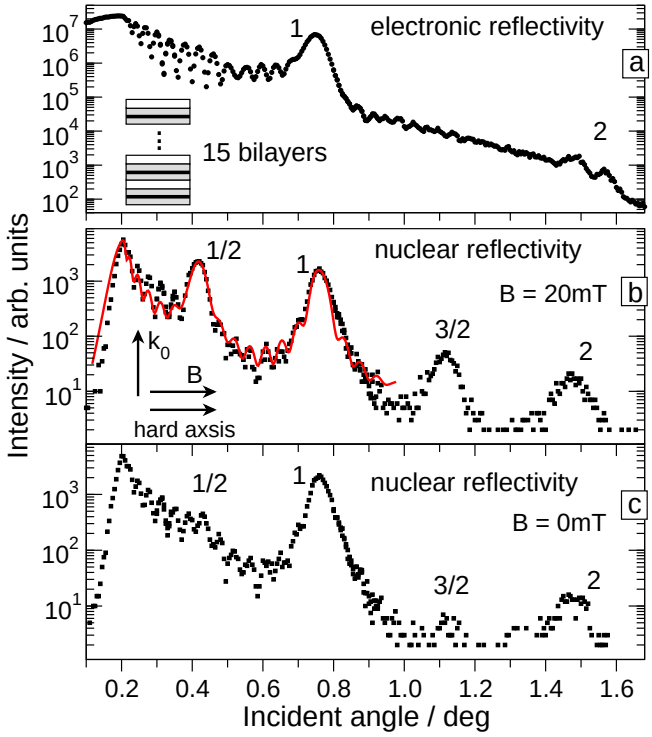

Fig. 2: Electronic (a) and nuclear reflectivities taken at 14.4 keV. The integer order Bragg peaks in the electronic reflectivity result from the chemical periodicity of the multilayer. In the nuclear reflectivity (b) half-order peaks appear due to a non-collinear alignment of the magnetic moments in adjacent iron layers. In this scattering geometry these peaks vanish for zero field (c), due to a reorientation of the magnetic moments.

From those results the question arises how the spin structure evolves with an increasing number of bilayers. In order to investigate the long-range order between the moments in the Fe layers, a multilayer stack ($[$Fe(1.7 nm)/Fe-oxide(1.6 nm)$]_{15}$) was prepared with a 0.6 nm thick ^{57}Fe layer embedded in the center of every Fe layer. The electronic reflectivity in Fig. 2a shows a pronounced first-order Bragg peak which arises due to the chemical periodicity of the superlattice. In an external field of $\vec{B}$ = 20 mT applied perpendicular to $\vec{k}_0$ (transverse geometry) and parallel to the hard axis , additional half-order Bragg peaks appear in the nuclear reflectivity (Fig. 2b) indicating a magnetic periodicity that is twice as large as the chemical one. From the simulation of the nuclear reflectivity we derive a canting angle of about 85° between adjacent iron layers. In remanence only a small residue of the half-order peak remains (Fig. 2c). Obviously, a reorientation of the moments has taken place where the difference in the projections of the moments on the direction of $\vec{k}_0$ vanishes. The half-order peaks appear again after rotation of the sample by 90°, indicating that the system do not break into magnetic domain in remanence. On the contrary it is found that the canting angle remain the same as for the 20 mT field situation. Precise study of the half-order Bragg peak intensity as function of field allowed us to conclude that the magnetization reversal on the hard axis take place by coherent rotation of the magnetic moment at a fixed coupling angle.

[1] Th. Diederich et al., submitted to Phys. Rev. Lett.