ESRF	**Experiment title:** Interface resolved nuclear forward scattering using superlattice standing wave field generators: Study of Boron diffusion in CoFeB based TMR tri-layer structures	**Experiment number**: MA-5362
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Report:

In this experiment, we have combined the X-ray standing wave field generator (XSWFG) approach along with nuclear resonant forward scattering (NFS), to investigate and especially disantangle the depth dependent magnetic spin structure and strenghth of magnetic hyperfine fields in two types of ^{57}Fe magnetic thin film systems.

For this purpose, we have prepared high quality Ta/SiC superlattices with atomically flat interfaces as substrate in our labs at DESY and adjusted the double layer period according to the thickness of the magnetic thin film system of interest placed above (3 nm/ 11 nm). The integration of intermediate spacer layers with linear thickness gradient in between the XSWFG and magnetic thin film system (see fig. 1) allowed us to selectively illuminate and thus study different depths of the nanofilms by simply collecting nuclear resonant time spectra at the first Bragg peak position of the XSWFG at various lateral positions of the sample (via stepwise perpendicular displacement of the sample relative to the incoming beam).

Unfortunately, due to technical problems, the originally proposed Co^{57}FeB thin film systems couldn’t be sucessfully enriched in ^{57}Fe anymore for this experiment which was due to a Covid refused approval on very short notice only (2 weeks before the beamtime slot). Instead, two other sample systems of at least identical relevance could be finalized and studied. In the first sample systems, we targeted to investigate the evolution of the strength of the magnetic hyperfine field in 3 nm thin ^{57}Fe films sandwiched in between different materials as a function of depth (Please refer fig. 1(a)). In the second sample system, a novel type of magnetic thin film with two customized crossed unidirectional magnetic anisotropy axes (on the top and bottom side of the ^{57}Fe film) was studied. The goal of this investigation was the detection of a magnetic spiral structure in a 11 nm thick iron film with 90° crossing of these both easy axes which were realized via the oblique incidence deposition technique (fig. 1(d)).

The results of this beamtime definitely excelled our expectations in view of the technical applicability of the combined XSWFG/NFS approach as well as the scientific results of both types of sample systems. The exceptional quality of the XSWFGs produced a very high reflected signal and a nearly 100% contrast in the standing wave field pattern generated above the superlattice. This allowed us to screen the first sample system which is a 3 nm thin iron film sandwiched in between Chromium and Carbon (later on abbreviated as Cr-Fe-C) with a high depth resolution in the sub-nm regime while harvesting sufficient statistics of the nuclear signal at the first Bragg peak position where the desired standing wave field pattern is formed. The electronic and nuclear resonant reflectivity of Cr-Fe-C are shown in fig.1 (b). Even without quantitative evaluation of all the time spectra (>100), we recognized various suprising/interesting effects already during the beamtime. As one example, 3 selected time spectra of the same Cr-Fe-C sample are shown in fig.1(c), in which a magnetically stabilized bottom part of the iron film close to the chromium contact layer can be seen while the top part of the iron in contact to the carbon is observed to be non-magnetic.

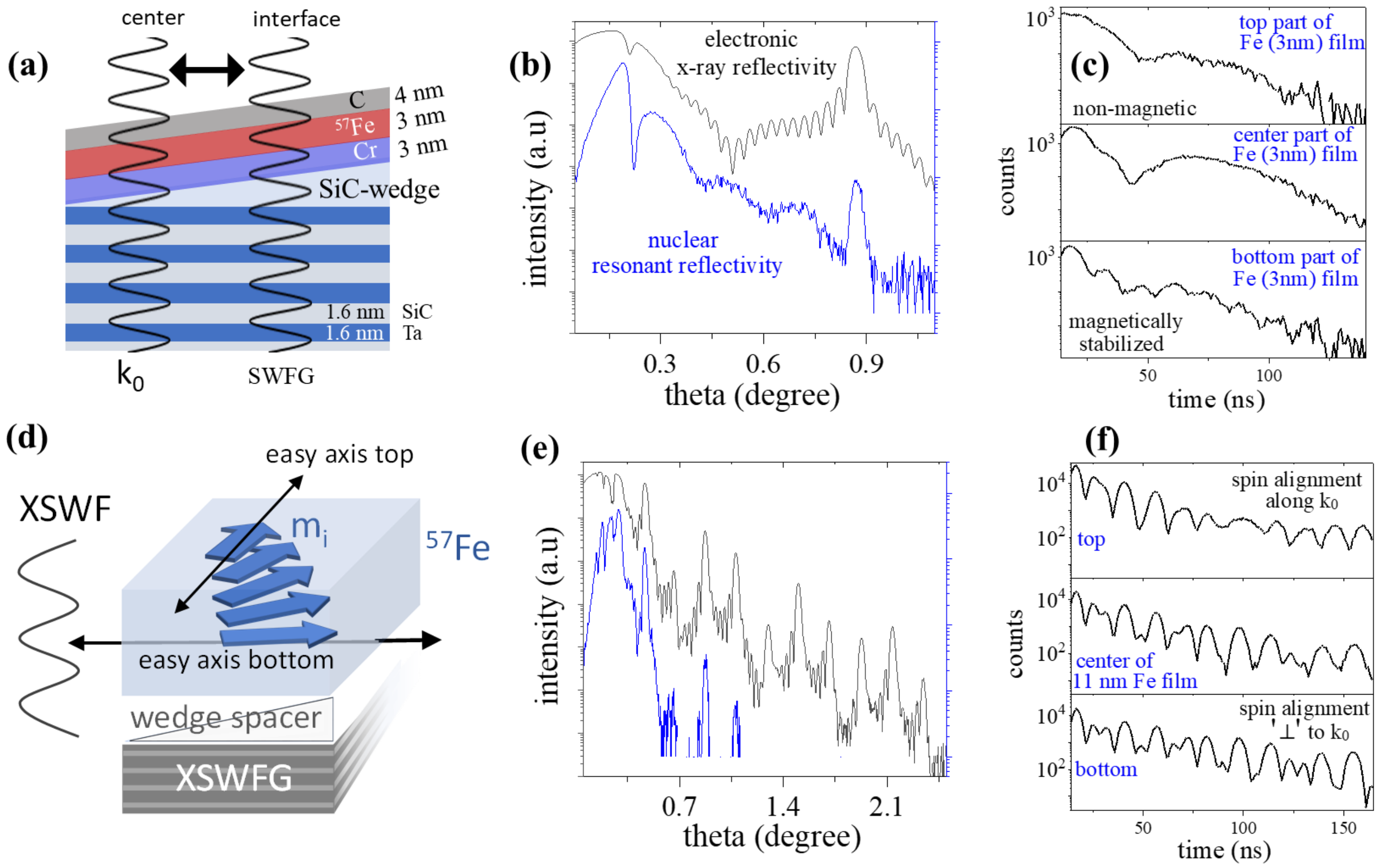

Figure 1: (a), (d) Schematic of Cr-Fe-C and OID-Fe samples respectively; (b), (e) Electronic X-ray reflectivity pattern (Black) and nuclear resonant reflectivity pattern (Blue) of Cr-Fe-C and OID-Fe samples respectively; (c), (f) Selected NFS time spectra of Cr-Fe-C (in presence of 20 mT magnetic field along k_0) and OID-Fe (recorded in remanance state after removal of 70 mT magnetic field along k_0) respectivily.

Also in the second (more technologically relevant) sample system labeled as OID-Fe, the desired effect of the custom-made static magnetic spiral structure in the 11 nm thick iron film with two seperated and 90° crossed magnetic anisotropy axes on both (top and bottom) parts of film can already clearly be recognized even without simulation. By moving an anti-node of the standing wave field pattern vertically through the film, a continous change of the time spectra (fig. 1 (f)) and thus orientation of the spin structure can be seen as illustrated in fig.1 (d). The spins close to the top surface seem to be oriented near to the direction of the beam (parallel to the imprinted unidirectional surface anisotropy) and in depth the spins are seen to be turn away from this axis and reach an orientation close to 90° to the beam direction on the bottom side of Fe film (in which the anisotropy axis in 90° geometry is imprinted).

In summary, we rate this experiment as extremely succesful in both, the technical and scientific aspects. During the beamtime we benefit from the very high nuclear flux at beamline ID18, the good stability of the nuclear resonance and the overall excellent user support by the beamline stuff. Only impurities of the filling mode (spurious/side bunches) which were repeatedly minimized by the machine group with the standard cleaning procedure partially reduced the quality of the collected time spectra.