Quantitative EMCD analysis of Fe thin films on MgOx substrates

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Background
The structure and electronic structure of interfaces determine their magnetic properties in many modern materials. Yet, X-ray and neutron-based analysis techniques, albeit their fantastic contributions to the field, cannot give the real space image of magnetization. And among the TEM techniques, the close-to-atomic scale analysis of magnetic interfaces remains a challenge. All three magnetic analysis techniques in the TEM, electron holography, Lorentz microscopy, and electron energy loss magnetic circular dichroism (EMCD) have now established the first results demonstrating that with TEM techniques, we can obtain magnetic information at this length scale [1-4]. In the EMCD technique, magnetic information originates from the interference of electrons inelastically scattered into different beams. This interference giving rise to the EMCD signal is appearing at well-defined and conjugated q-vectors called C+ and C- positions. It bears an intensity that can be interpreted as resulting from the orbital and spin magnetic moments of the involved magnetic atoms. The technique can address both ferro- and antiferromagnetic materials.

Here, we present EMCD measurement on thin Fe films on MgOx substrate and show how accurate alignment and experimental parameters like convergence and collection angles modify the EMCD signal and interpret this change in magnetic signal to obtain magnetization and orbital/spin magnetic moment ratio in the Fe and at the Fe/MgO interface.

Methods
Fe films were grown on MgOx (001) substrate by sputter deposition. The cross-sectional and plan view samples were analysed using the EMCD technique in STEM mode. Spectra of the L3 and L2 edge of Fe corresponding to the C+ and C- positions were acquired at 2 beam condition using a Titan/Themis probe corrected TEM at an acceleration voltage of 200 - 300 kV with Gatan energy filter and a CEFID energy filter equipped with a direct electron camera ELA. The q-selection of the EELS spectra was carried out by using a custom-made script to shift the diffraction pattern and by placing a slit aperture into the EELS entrance aperture holder, see schematic Figure below. Each acquisition contains between 2000-10000 spectra which enables the treatment of individual spectra or sum spectra as well as the use of statistical methods in data analysis.

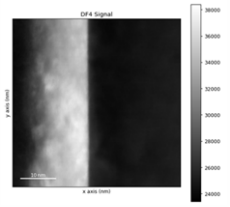
Results
Refinements of both, EELS analysis conditions as well as the sample quality enables us to improve the EMCD signal strength from the original paper of around 4 % to 17 % as shown in the figure below, which was taken at small convergence angle and using the conventional circular EELS entrance aperture. Though, aiming to approach atomic resolution in magnetic measurements, high convergence angles in the EMCD analysis are needed, which will be

typically larger than 5 mrad. The other limit of such EMCD analysis is beam damage. We analysed the EMCD signal as a function of convergence angle and optimized acquisition conditions in view of limiting beam damage. With those conditions, we analyse EMCD signals at the Fe/MgOx interface with down to 2Å resolution [4,5].

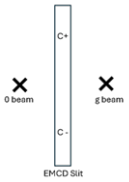
Conclusion

In summary, we have optimized and analysed signals in EMCD measurements on Fe/MgOx . An excellent EMCD difference signal as well as improvement in the signal-to-noise ratio is evident due to the crystalline quality. We have obtained interfacial profiles of EMCD signals with down to 2Å resolution.

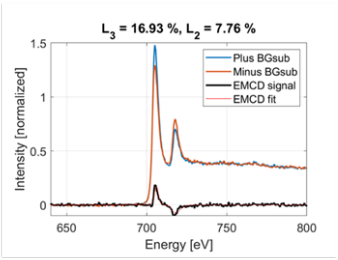
Graphic:



ADF image showing Fe film on the MgOx substrate



EMCD experimental condition showing the 0 and the g beam (Fe 200) with the slit aperture



Background subtracted and normalized C+ and C-spectra with the EMCD difference signal

Keywords:

EMCD, HRSTEM, Magnetic measurement.

Reference:

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