ESRF	**Experiment title:** **Grain growth induced by focused ion beam irradiation in thin magnetic films**	**Experiment number**: 20-02-696
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Report:

Over the last decade there is a rise of interest in fabrication and study of nanometer size magnetic elements that are widely used for magnetic recording media. Combination of focused ion beam with lithography (FIB lithography) can be used as a comprehensive tool for magnetic nanostructuring. Previous studies have demonstrated that FIB irradiation of thin metallic films induces significant grain growth and modifies the magnetic properties[1-2]. However in order to use FIB irradiation for nanostructuring one needs high Ga$^+$ ion fluences up to 2000µC/cm^2, leading to irradiation times of about 5 up to 98 hours for the area size of 0.4x0.4mm^2. As a result due to the small irradiated areas produced by FIB irradiation CRL beryllium lenses were applied to focus the beam down to 20µm.

The aim of this experiment was to study the structure of magnetic metallic films after 30keV Ga$^+$ FIB irradiation by the EXAFS measurements. The main advantage of the EXAFS analysis is precise short-range order structural information. Such information in combination with XRD data is needed for understanding weather any relationship between the structure and magnetic properties takes place. We have investigated a series of 50nm thick permalloy ($Ni_{80}Fe_{20}$) films irradiated with different Ga$^+$ ion fluences.

Prior to the EXAFS measurements an XRD analysis was performed. A set of rocking curves and in-plane rotation measurements using a position sensitive detector were carried out. From the rocking curve measurements we found out that fluences up to 1000µC/cm^2 modify the material and induce the crystalline growth (from 13nm for the non-irradiated sample up to 23nm for the sample irradiated with 1000µC/cm^2). The in-plane rotation measurements have demonstrated an increased ordering towards a (111) texture of the material induced by irradiation. The magnetic properties were measured via MOKE magnetometry and demonstrate degradation with increasing the ion fluence.

Integral raw XAS spectra of the Fe *K* (figure 1), Ni *K* (figure 2) and Ga *K* (figure 3) absorption edges of the permalloy film before (black) and after (red) irradiation are presented. Due to the fact that in the investigated permalloy film the lattice positions are randomly occupied by Fe or Ni and the low signal-to-noise ratio at the Fe edge (Fig.1) the date of the Fe *K* edge were not further taken into account. Subsequently, analysis of the EXAFS data was performed only for Ni *K* (Fig.2) and Ga *K* (Fig.3) edges. The measurements were first smoothed and a background subtraction was performed using ATHENA software. The data refinement was further performed using ARTEMIS software based on the FEFF6 code. Figure 4 demonstrates the extracted experimental EXAFS function $\chi(k)$ weighted to the wave number k^2 for Ni *K* edge of samples irradiated with 735µC/cm^2 and 1000µC/cm^2 fluences. The red line corresponds to the simulation. The simulation didn't show any distinguishable difference in parameters since no significant changes are observed in extracted EXAFS function $\chi(k)$ for the Ni *K* edge. The Ni *K* edge fits demonstrate negligible deviations of the lattice parameter from its nominal value of 3.55 Å as well as very small atom displacements within the simulation errors at different irradiation fluences. The fitting performed for the Ga *K* edge requires a model being not attached to a fixed crystallographic symmetry (an almost amorphous material case).

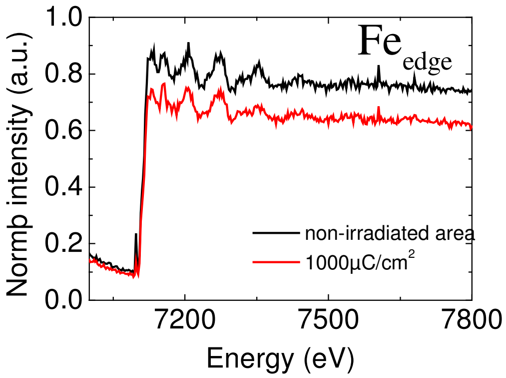

Figure 1. Normalized integral raw XAS spectra of the Fe *K* absorption edge of the permalloy film before (black) and after (red) irradiation.

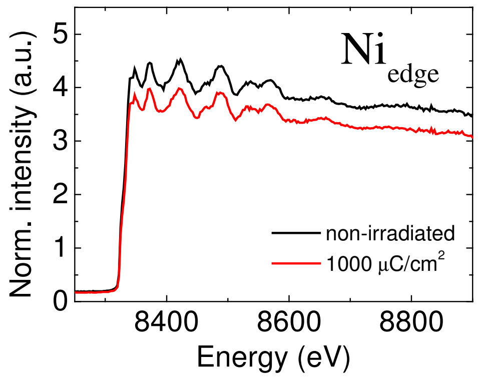

Figure 2. Normalized integral raw XAS spectra of the Ni *K* absorption edge of the permalloy film before (black) and after (red) irradiation

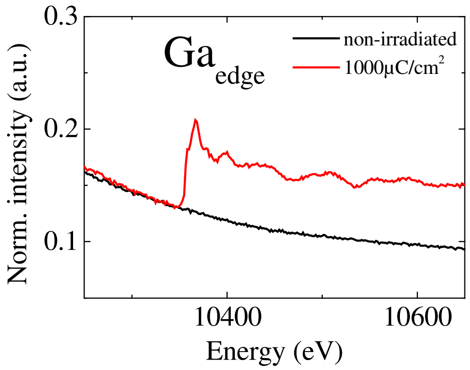

Figure 3. Normalized integral raw XAS spectra of the Ga *K* absorption edge of the permalloy film before (black) and after (red) irradiation.

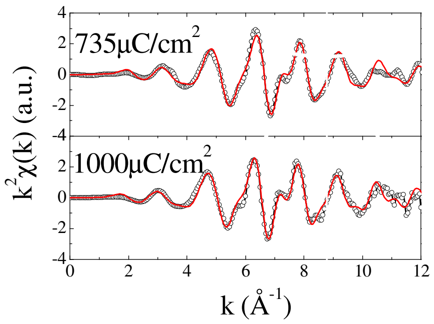

Figure 4. Extracted experimental EXAFS function $\chi(k)$ of the samples irradiated with 735µC/cm^2 and 1000µC/cm^2 weighted by k^2 at the Ni *K* edge.

Our investigations let us propose the following: FIB irradiation modifies the material and leads to a further material crystallization and to an incorporation of Ga^+ ions, however the simulation of the EXAFS data for the Ga *K* edge demonstrates that Ga atoms are not incorporated in perfect fcc cells but may remain outside, e.g. in the grain boundaries.

References

[1] C.M. Park and J. A. Bain., J. of Appl. Phys. 91, 6830 (2002).
[2] W.M. Kaminsky et al., Appl. Phys. Lett. 78, 1589 (2001).
[3] O. Roshchupkina, J. Grenzer, M. Fritzsche, J. Fassbender, DPG Regensburg 2010, DS 36.2.
[4] O. Roshchupkina, J. Grenzer, M. Fritzsche, J. Fassbender, XTOP 2010, B59.