ESRF	Experiment title: **Grain growth induced by focused ion beam irradiation in thin magnetic films**	**Experiment number**: 20-02-700
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Report:

This experiment is a continuation of the experiment № 20-02-696.

Previously it was demonstrated that nanoscale patterning can be performed using focused ion beam (FIB) techniques combined with lithography. Such a combination is known as FIB irradiation and is similar to standard implantation. FIB irradiation source differs from a standard ion implanter in a very small beam size of ~10nm in diameter and in a very high beam current density of ~ 12.7A/cm^2. Both beam size and beam current density can lead to difference in interaction of the ion beam with the matter changing both structural and magnetic properties. As a result detailed structural investigations of both irradiation cases are of great importance to understand the processes that take place while irradiation. In previous studies by C.M. Park and J.A. Bain (Ref. 1) it was demonstrated that FIB irradiation of permalloy films under certain conditions induces a significant grain growth. W.M. Kaminsky and co-authors (Ref. 2) have shown that FIB irradiation causes a degradation of magnetic properties with increasing the Ga^+ ion fluence.

In this experiment we have studied the structure of magnetic metallic films irradiated with Ga^+ ions by a standard implanter at the energy of 30keV. The main goal of this experiment was EXAFS measurements providing precise local structural information. Such information in combination with XRD data is needed for understanding the difference between FIB irradiation and standard implantation, in particular which parameters play the main role while irradiation. We have investigated a series of 50nm thick permalloy ($Ni_{80}Fe_{20}$) films irradiated with different Ga^+ ion fluences (the fluences were similar to the FIB irradiated samples).

Prior to the EXAFS measurements an XRD analysis was performed. A set of rocking curves using a position sensitive detector were carried out at the laboratory setup. From the rocking curve measurements we have estimated the crystallites size showing a growth at higher fluences (from 13nm for the non-irradiated sample up to 19nm for the sample irradiated with 1000μC/cm^2). Moreover the rocking curves have demonstrated an increased ordering towards the (111) texture of the material induced by irradiation. MOKE magnetometry measurements demonstrate degradation of the magnetic properties with increasing ion fluence. Both results demonstrate similarity to the FIB irradiated samples.

Integral raw XAS spectra of the Fe *K* (Fig. 1) and Ni *K* (Fig. 2) absorption edges of the permalloy film for the samples irradiated with 1000μC/cm^2 (black) and 4000μC/cm^2 (red) fluences are presented. Figure 3 demonstrates Ga *K* edge for the samples irradiated with 400μC/cm^2 (blue) and 4000μC/cm^2 (red).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 data of the Fe *K* edge were not further taken into account. As a result the EXAFS data analysis 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 1000μC/cm^2 and 4000μC/cm^2 fluences. The red line corresponds to the simulation. Since no significant changes are observed in extracted EXAFS function χ(k) for different irradiation doses for the Ni *K* edge the corresponding simulation didn't show any distinguishable difference in parameters. 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). Both fitting results are similar to the FIB irradiation.

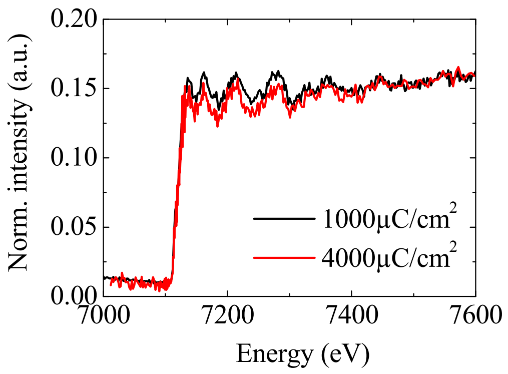

Figure 1. Normalized integral raw XAS spectra of the Fe *K* absorption edge of the permalloy film irradiated with 1000μC/cm^2 (black) and 4000μC/cm^2 (red) fluence.

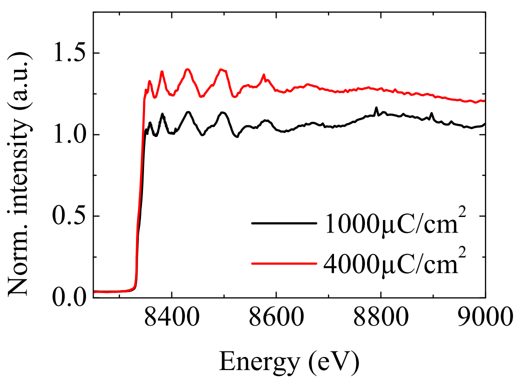

Figure 2. Normalized integral raw XAS spectra of the Ni *K* absorption edge of the permalloy film irradiated with 1000μC/cm^2 (black) and 4000μC/cm^2 (red) fluence.

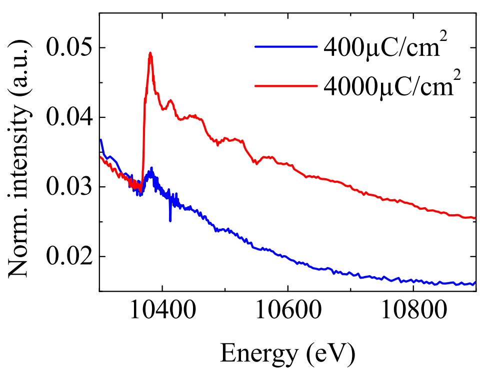

Figure 3. Normalized integral raw XAS spectra of the Ga *K* absorption edge of the permalloy film irradiated with 400μC/cm^2 (blue) and 4000μC/cm^2 (red) fluence.

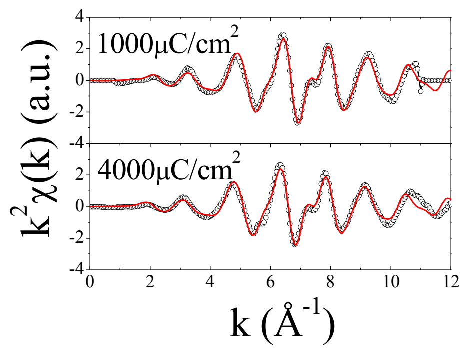

Figure 4. Extracted experimental EXAFS function χ(k) of the samples irradiated with 1000μC/cm2 and 4000μC/cm2 weighted by k^2 at the Ni *K* edge.

Our investigations let us propose the following: standard implantation 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. As a conclusion standard implantation demonstrates similar behaviour in comparison to the FIB irradiation.

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.