ESRF	**Experiment title:** **Grain growth induced by focused ion beam irradiation in thin magnetic films**	**Experiment number:** **20-02-712**
Beamline: BM20	**Date of experiment:** from: 15-06-2011 to: 17-06-2011	**Date of report:** 20-12-2012
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Report:

This experiment is a continuation of the experiments № 20-02-696 and № 20-02-700.

In previous works it was demonstrated that nanoscale patterning can be done using focused ion beam (FIB) techniques. In comparison to standard ion implanter, FIB technique is a mask-free technology, therefore, reducing the number of technological steps for producing nanostructures. FIB techniques differ from standard ion implanters in their very small beam sizes and, subsequently, in very high beam current densities. High beam current density can lead to a rise of the local temperature in the film during ion implantation leading to changes in both structural and magnetic properties. As a result detailed structural investigations of both irradiation techniques are of great importance to understand the processes that take place during implantation. C.M. Park and J.A. Bain (Ref. 1) have 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 results in a decrease of the saturation polarization with increasing Ga^+ ion fluence.

In this experiment we have studied the structure of thin magnetic metallic films irradiated with Ga^+ ions using a FIB technique and a standard implanter at the energy of 30keV. The main goal of this experiment was the 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 ion implantation. Moreover, EXAFS is the only method which allows to define the positioning of the implanted Ga atoms in the film.

Prior to the EXAFS measurements an XRD analysis was performed. A set of rocking curves around the (111) permalloy reflection using a position sensitive detector (PSD) were carried out at the laboratory setup. From the rocking curve measurements for both FIB and standard ion implanter it was found that the crystallite size is increasing with increasing ion fluence (from 13nm for the non-irradiated sample up to 20nm for the samples irradiated with ion fluences $\geq 6.24 \times 10^{15}$ ions/cm^2). Moreover, rocking curves demonstrated an increasing (111) orientation with increasing ion fluence. MOKE magnetometry measurements demonstrate a decrease of the saturation polarization with increasing ion fluence. Results obtained for the samples implanted with a FIB technique and with a standard ion implanter are similar.

In Figures 1 and 2 integral raw XAS spectra of the Ga *K* absorption edges of the permalloy films irradiated at different ion fluences with a FIB technique and with a standard ion implanter, respectively, are demonstrated (the Ni *K* and Fe *K* edges are here not shown). The Fe *K* edges were not analysed due to very low signal-to-noise ratio. As a result the EXAFS data analysis was performed only for Ni *K* and Ga *K* 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. The model used for the simulation of the EAFS spectra represents an isotropically strained fcc unit cell. Figures 3 and 4 demonstrates changes of the lattice parameter (Δa) extracted from the XRD measurements (black) compared to changes of the lattice parameter obtained from the simulation of the Ni *K* (red) and Ga *K* (blue) edges for the samples implanted with a FIB technique and with a standard ion implanter, respectively. From the results shown in Figures 3 and 4 it can be concluded that values of Δa obtained from the EXAFS measurements are in a good agreement with the ones obtained from the XRD measurements.

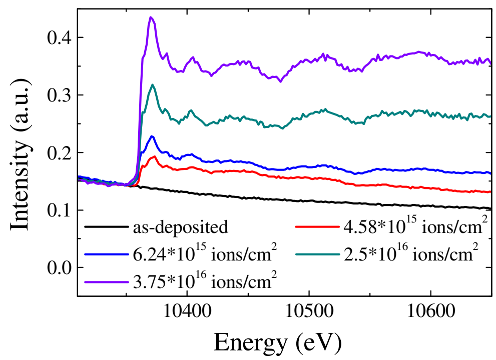

Figure 1. Normalized integral raw XAS spectra of the Ga *K* absorption edge of the permalloy film irradiated with a FIB technique at different ion fluences.

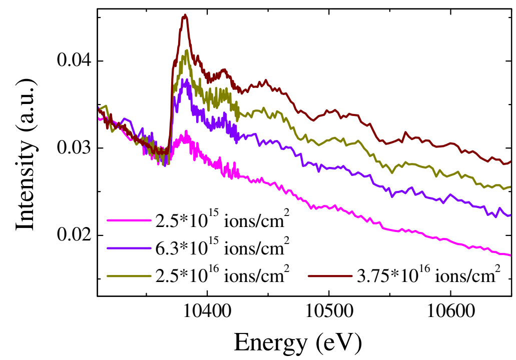

Figure 2. Normalized integral raw XAS spectra of the Ga *K* absorption edge of the permalloy film irradiated with a standard ion implanter at different ion fluences.

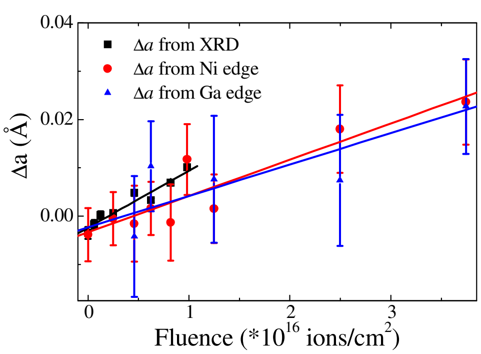

Figure 3. Change of the lattice parameter (Δa) extracted from the XRD measurements (black) and from the simulation of the Ni *K* (red) and Ga *K* (blue) edges for the samples implanted with a FIB technique.

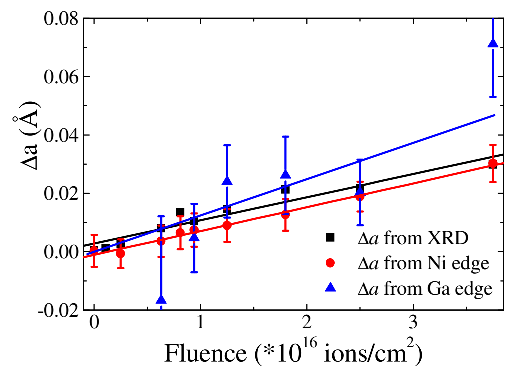

Figure 4. Change of the lattice parameter (Δa) extracted from the XRD measurements (black) and from the simulation of the Ni *K* (red) and Ga *K* (blue) edges for the samples implanted with a standard ion implanter.

Our investigations let us propose the following: both FIB irradiation and standard implantation modifies the material and leads to a further material crystallization and material texturing. From the measured Ga *K* edges and corresponding simulation for both implantation techniques follows that Ga atoms are incorporated in the unit cells with an fcc symmetry. As a conclusion FIB irradiation demonstrates similar behaviour in comparison to the standard ion implantation.

References

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