GaMnAs is considered as a promising material for novel spintronic applications. The uniform ternary alloys as well as related material containing inclusions of ferromagnetic MnAs have been intensively investigated. It was found, in particular, that nanosized MnAs ferromagnets buried in GaAs can be obtained not only by the MBE method but also by Mn ion implantation into GaAs wafers. On the other hand, other types of inclusions, like MnSb, also show promising magnetic properties at room temperature and it is possible to obtain such inclusions during the MBE growth. However, the implantation method is also well established, but cheaper and easier to carry out within the industrial production process. Therefore, it would be important to find an optimal way of producing the MnSb inclusions with the desirable properties by Mn ions implantation as it has been done in the MnAs case.

In this report we focus on the GaSb (100) crystals implanted with Mn ions. The implantation energy was equal to 10 keV and the doses of Mn ions were 1x10^{16} Mn/cm^2, 2x10^{16} Mn/cm^2 and 3x10^{16} Mn/cm^2. After the implantation all samples were annealed in a vacuum furnace at 650ºC for 10 min.

Extended X-ray Absorption Fine Structure (EXAFS) measurements at the K edge of Mn were performed at A1 and E4 stations at liquid nitrogen temperature in a fluorescence mode using a 7-element silicon detector. EXAFS analysis was conducted using IFEFFIT data analysis package with Athena and Artemis programs [1].

![Figure 1: Fourier transform of the EXAFS spectrum and theoretical models based on GaSb crystal with Mn substituting Sb. Spectra are shifted vertically for clarity.](image1)

![Figure 2: Fitting results of the EXAFS spectra up to the second coordination shell. Residual Sb atoms were added during fitting. Spectra are shifted vertically for clarity.](image2)
Preliminary EXAFS analysis revealed that the first coordination shell consists of gallium atoms. It excludes the possibility that Mn substitutes Ga atoms in the GaSb matrix as well as that MnSb compound is formed.

In Figure 1 the magnitude of Fourier transformed EXAFS oscillations of the sample with the lowest Mn content and three theoretical models based on GaSb structure are presented. In the first one, "Mn in GaSb matrix", Mn central atom is located in the Sb position. The comparison demonstrates that this model differs considerably from the experiment which suggests that there is a deficit of Sb atoms in the Mn neighborhood. In the next model, "without Sb sublattice", according to the name all the Sb atoms were removed. In this case, the result seems to resemble the experimental spectrum better but the distances to the subsequent shells are too large. On the other hand, with a lack of antimony atoms, it can be expected that remaining Ga atoms rearrange their positions and move closer to the central atom. Therefore, in the last model, "contracted Ga sublattice", the distances to the consecutive coordination shells were multiplied by a contraction factor ~0.92.

In Figure 2 the results of fitting for the samples with all doses are shown. In each case, two coordination shells were considered. Both of them consist of gallium atoms, however, some residual antimony atoms are also found between the shells. The distances to the first and second gallium coordination shell in the ideal GaSb crystal are equal to 2.65Å and 5.07Å. From fitting with the "contracted Ga sublattice" model, they were found to be around 2.42 Å and 4.64 Å, respectively.

EXAFS analysis showed that even low energy implantation and quick annealing leads to the significant deficit of Sb atoms around implanted Mn atoms. Moreover, Mn atoms are located in the antimony positions in the GaSb matrix where Sb sublattice is almost completely destroyed and the remaining Ga sublattice contracts significantly. However, it concerns only Mn surrounding. X-ray diffraction did not indicate significant changes in lattice parameters in the studied samples.

This work was partially supported by national grant of Ministry of Science and High Education N202-052-32/1189. The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 226716.

References