GaSb Crystals Implanted with Mn Ions - Mn K-edge study

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Our previous work [1] showed that forming the MnSb inclusions in the GaSb substrates during Mn ion implantation encounters many obstacles. Implantation tends to remove Sb atoms from the Mn atoms' neighborhood and the Mn atoms prefer to bond to Ga or O atoms. Therefore, several processes with more steps were investigated in order to look for the proper procedures.

The samples were prepared by co-implantation of the Ne⁺, He⁺, Mn⁺ and Sb⁺ ions into the GaSb(100) crystals. The He⁺ and Ne⁺ ions were used to make the matrix disordered in order to prevent the penetration of oxygen and the escaping of Sb atoms. The energy and doses of Mn and Sb ions were chosen according to the depth profile ion distribution simulated by code SRIM2008 [2] in order to locate the Mn and Sb ions at the distance from 50 to 150 nm from the surface i.e. within amorphous region. In some of samples additional Sb⁺ ions were introduced to increase amount of Sb and to prevent Mn bonding with oxygen or gallium. The substrates' temperature during the implantation processes was kept at 80K. The implantation of noble gases was not supposed to influence the GaSb matrix density. Four series of implantation were performed:

1. NeMn where the substrate was implanted with Ne⁺ ions (250 keV, dose 5x10¹⁶ cm⁻²) first and then with Mn⁺ ions (150 keV, dose 9x10¹⁴ cm⁻²).

2. NeMnSb where after the procedure described above the Sb⁺ ions (250 keV, dose 9x10¹⁴ cm⁻²) were added.

3. HeMn where the substrate was implanted with He⁺ ions (80 keV, dose 5x10¹³ cm⁻²) first and then with Mn⁺ ions (150 keV, dose 9x10¹⁴ cm⁻²).

4. HeMnSb where after the procedure described above the Sb⁺ ions (250 keV, dose 9x10¹⁴ cm⁻²) were added.

![XANES of the samples annealed at 350°C compared with MnSb standard spectrum.](image)
Each of the implanted samples was subsequently divided into three parts. One part was left as such, the second part was subject to rapid thermal annealing for 5 min in the Ar atmosphere at the temperature 350°C and the third one at 400°C.

X-ray Absorption Fine Structure (XAFS) measurements at the K edge of Mn were performed at A1 station at liquid nitrogen temperature in a fluorescence mode using a silicon drift detector (SDD).

Figure 1 presents the XANES spectra of the samples annealed at 350°C compared with the MnSb standard spectrum. The shapes of the spectra of the investigated samples are quite similar to each other. However, the possibility of MnSb formation has to be excluded since they are significantly different from the MnSb spectrum. The same can be concluded for the as-implanted and annealed at 400°C samples.

![Figure 1: XANES spectra of the samples](image)

Figure 2: Magnitude of Fourier Transform of the EXAFS spectra of the samples annealed at 350°C compared with the MnO standard.

More specific information about the local neighborhood of the Mn atoms can be obtained from the EXAFS analysis. As can be seen in Figure 2, the Mn neighborhood is rather amorphous, only the first shell consisting of oxygen atoms is formed. The MnO standard spectrum is shown for comparison. It reveals that performed procedures did not prevent Mn atoms to be bonded with oxygen. The reason of that can be low temperature during the implantation process.

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**References**
