*ISSRNS 2010: Extended abstracts / Synchrotron Radiation in Natural Science Vol. 9, No. 1 – 2 (2010)*

# ANOTHER APPROACH TO THE Mn ION IMPLANTATION INTO THE GaSb CRYSTALS

**A. Wolska [1*], K. Lawniczak-Jablonska [1], M.T. Klepka [1], M. Kulik [2], and R. Jakiela [1]**

*[1] Institute of Physics PAS, al. Lotników 32/46, 02-668 Warsaw, Poland*

*[2] Institute of Physics, University Maria Curie-Skłodowska, Pl. Marii Curie Skłodowskiej 1, 20-031 Lublin, Poland*

*Keywords: XAFS, implantation, GaSb*

**) e-mail: wolska@ifpan.edu.pl*

The quest for materials ferromagnetic at room temperature that can be used for spintronic applications is still going on. Different compounds obtained with different methods are investigated. One of the most popular materials is GaMnAs. It has been examined in the form of the uniform ternary alloys as well as the material containing precipitations of ferromagnetic MnAs. The interest in precipitations opened the way for the implantation methods. Different types of magnetic inclusions ($Ga_xMn_y$, MnAs hexagonal and GaMnAs cubic) were formed in the GaAs crystals depending on the applied Mn ion energy, dose and post implantation annealing procedures [1,2]. On the other hand, also MnSb inclusions show promising magnetic properties at room temperature. It is possible to obtain such inclusions during the MBE growth but the implantation method is 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.

Unfortunately, the recipe for the formation of the MnSb inclusions in the GaSb substrates during Mn ion implantation is not simple. Implantation tends to remove Sb atoms from the Mn atoms' neighborhood and the Mn atoms prefer to bond to Ga or O atoms [3]. Therefore, processes with more steps should be investigated in order to establish 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 escape of Sb atoms. The substrates' temperature during the implantation processes was kept at 80 K. Four series of implantation were prepared:

1. *NeMn* where the substrate was implanted with $Ne^+$ ions (250 keV, dose $5\times10^{16}$ $cm^{-2}$) first and then with $Mn^+$ ions (150 keV, dose $9\times10^{14}$ $cm^{-2}$).
2. *NeMnSb* where after the procedure described above the $Sb^+$ ions (250 keV, dose $9\times10^{14}$ $cm^{-2}$) were added.
3. *HeMn* where the substrate was implanted with $He^+$ ions (80 keV, dose $5\times10^{13}$ $cm^{-2}$) first and then with $Mn^+$ ions (150 keV, dose $9\times10^{14}$ $cm^{-2}$).
4. *HeMnSb* where after the procedure described above the $Sb^+$ ions (250 keV, dose $9\times10^{14}$ $cm^{-2}$) were added.

The energy and doses of Mn and Sb ions were chosen according to the depth profile ion distribution simulated by code SRIM2008 [4,5] in order to locate the Mn and Sb ions in the distance from 50 to 150 nm from the surface. The implantation of noble gases was not supposed to influence the GaSb matrix density.

Each of the implanted samples was subsequently divided in 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.

The X-ray Absorption Near Edge Structure (XANES) and Extended X-ray Absorption Fine Structure (EXAFS) measurements at the Mn K-edge were carried out at Hasylab (A1 station) in fluorescence mode using a silicon drift detector. The samples were cooled to liquid nitrogen temperature in order to minimize thermal disorder. In order to check the distribution of the atoms in the crystals, the Secondary Ion Mass Spectroscopy (SIMS) measurements using a CAMECA IMS6F micro-analyzer were also carried out.

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.

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.

The distribution of the elements in the *NeMnSb* sample annealed at 350°C measured by SIMS is presented in Figure 3. SIMS data confirm that high amount of oxygen was introduced during the procedure and, as it was shown above, this resulted in formation of Mn oxides.

Concluding, it seems like the implantation into the cold and amorphous substrate prevented the Sb atoms from escaping but still the oxygen atoms were incorporated deeply into the matrix and the Mn oxides were formed.

**Acknowledgements:** 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.

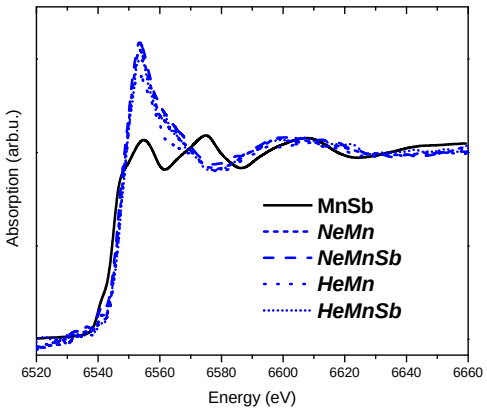


Figure 1. XANES of the samples annealed at 350°C compared with MnSb standard spectrum.

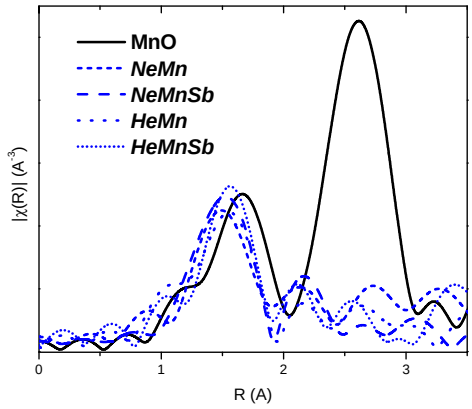


Figure 2. Magnitude of Fourier transform of the EXAFS spectra of the samples annealed at 350°C compared with the MnO standard.

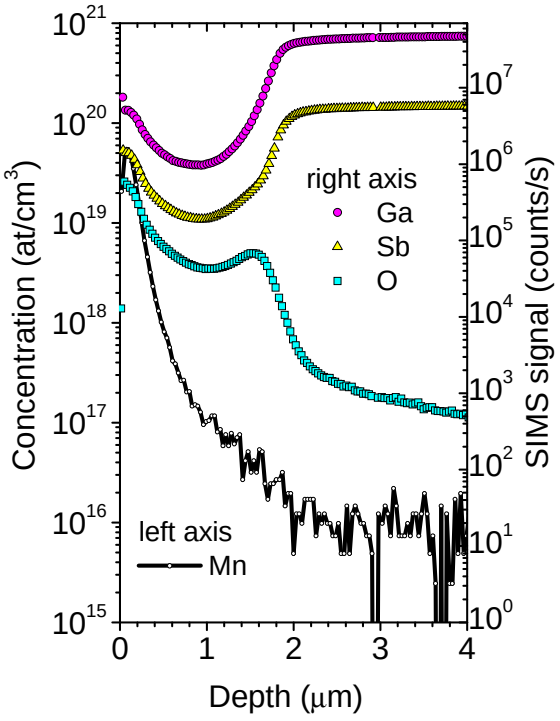


Figure 3. SIMS depth profiles of the element distribution in the *NeMnSb* sample annealed at 350°C.

**References**

[1] C. Chen, M. Cai, X. Wang, S. Xu, M. Zhang, X. Ding, Y. Sun, "Ferromagnetic properties and structures of the Mn-implanted GaAs semiconductor", *J. Appl. Phys.* **87** (2000) 5636–5638.

[2] S.-L. Songa, N.-F. Chen, J.-P. Zhou, Z.-G. Yin, Y.-L. Li, S.-Y. Yang, Z-K. Liu, "Mn implanted GaAs by low energy ion beam deposition", *J. Cryst. Growth* **264** (2004) 31–35.

[3] A. Wolska, K. Lawniczak-Jablonska, M.T. Klepka, A. Barcz, A. Hallen, D. Arvanitis, "Study of the local environment of Mn ions implanted in GaSb", *Acta Phys. Polon. A* **117** (2010) 286–292.

[4] J.F. Ziegler, J.P. Biersack, U. Litmar, *The Stopping and Range of ions in Solid,* (Pergamon Press, New York, Oxford, Toronto Sydney, Frankfurt Tokyo 1985).

[5] J.F. Ziegler, J.P. Biersack, D.M. Ziegler, *SRIM The stopping and range of ions in solid*, (SRIM Co. 2835 Cox Nec Rd.Chester, Maryland, 21619 U.S.A.).