



Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office using the **Electronic Report Submission Application:**

<http://193.49.43.2:8080/smis/servlet/UserUtils?start>

Reports supporting requests for additional beam time

Reports can now be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.



	Experiment title: X-ray diffraction analysis of the structure of epitaxial layers of ferromagnetic semiconductors	Experiment number: SI1276
Beamline: ID32	Date of experiment: from: Nov. 2, 2005 to: Nov. 8, 2005	Date of report: Feb. 21, 2006
Shifts: 8	Local contact(s): Dr. Tien-Lin LEE	<i>Received at ESRF:</i>
Names and affiliations of applicants (* indicates experimentalists): Václav Holý*, Department of Electronic Structures, Charles University, Ke Karlovu 5, 121 16 Prague, Czech Republic Zdeněk Matěj*, Department of Electronic Structures, Charles University, Ke Karlovu 5, 121 16 Prague, Czech Republic Oliva Pacherová*, Institute of Physics, Czech Acad. Sci., Cukrovarnická 10, 162 53 Prague, Czech Republic		

Report:

Ferromagnetism in GaMnAs is intensively studied because of prospective applications of GaMnAs in spintronics (see [1], for instance). Ferromagnetism of the Mn spins is mediated by holes in a p-type GaMnAs. On the other hand, Mn atoms in interstitial positions give rise to donor levels in the energy gap and therefore they violate the ferromagnetic ordering and decrease the Curie temperature. Theoretical calculations predicted that a ferromagnetic state of GaMnAs could be achieved at room temperature for lattice-Mn content above 10% [1,2]. A growth of a GaMnAs layer having the Mn atoms in lattice positions is extremely difficult because of a very low solubility of Mn. In order to prevent the creation of MnAs precipitates, a molecular-beam epitaxy growth of GaMnAs has to be performed at extremely low temperature (of about 200-250°C) [3].

X-ray diffraction has been used for the determination of the concentrations of Mn lattice and interstitial atoms by measuring lattice misfit or structure factor of GaMnAs. These methods, however, are not reliable, because the dependence of the lattice parameter of GaMnAs on these concentrations is still under investigation [4,5]. In our experiment, we have used the x-ray standing wave method (XRSW) to determine the relative concentration of Mn lattice atoms and interstitials. In this method, the x-ray fluorescence MnK stemming from the Mn atoms is measured as a function of the incidence angle of primary radiation.

We have used the primary radiation with the energy 10 keV, the fluorescence signal was measured by a Roentec detector placed close to the sample surface. We have investigated a series of 4 samples of 100 nm thick GaMnAs layers with nominally 5% Mn deposited at 240°C at GaAs(001). After the growth the samples were annealed at 200°C for 0, 1 2 and 4 hours in the air. The layers were tetragonally distorted, having the same lateral lattice parameter as the GaAs substrate underneath. Due to this fact, the XRSW method was performed in a grazing-incidence (GID) geometry, in which the diffraction vector was parallel to the sample surface; we have used the strong diffractions 400, 220 and the quasi-forbidden diffractions 200 and 420. In each XRSW scan, the intensity of the MnK fluorescence was measured as a function of the azimuthal direction of the primary beam keeping constant the incidence angle α_i of the primary radiation. The scans were carried out for various values of α_i below and above the critical angle of total external reflection. Examples of experimental results are shown in Fig. 1 along with their theoretical fits.

In order to analyze the experimental XRSW curves we have simulated the fluorescence yield for several positions of the Mn atoms in the GaAs unit cell as well as for randomly distributed atoms in the cell. This simulation was based on dynamical diffraction theory in GID geometry taking into account the absorption of the fluorescence radiation in GaMnAs. In the simulation we have also assumed a nonhomogeneous distribution of the Mn atoms across the layer thickness, this nonhomogeneity however turned to be very small.

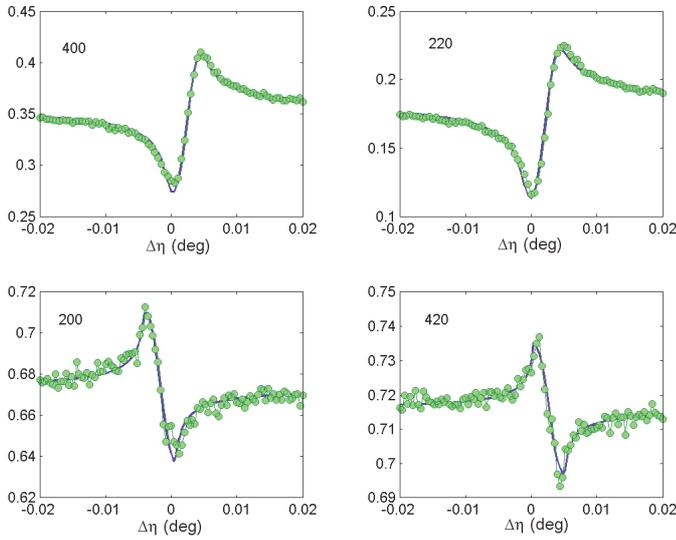


Fig. 1. The XRSW scans measured in 4 different diffractions in the GID geometry, non-annealed sample (points) and their fits by dynamical diffraction theory (lines). $\Delta\eta$ denotes the azimuthal deviation of the primary beam from the diffraction maximum.

In a GID geometry, the XRSW signal is sensitive only to the lateral coordinates of the Mn atoms. Therefore, it is principally impossible to distinguish between the Mn atoms in lattice and interstitial positions, since the energetically favorable Mn interstitials (with As atoms in the neighborhood) have the same lateral coordinates as the Mn atoms in lattice places (i.e., substituting Ga atoms). However, the GID-XRSW measurement is sensitive to the presence of randomly placed Mn atoms (such as Mn in MnAs inclusions). Figure 2 shows the XRSW scans calculated for constant α_i for substitutional Mn and randomly placed Mn atoms in diffractions 400, 220, 200 and 420.

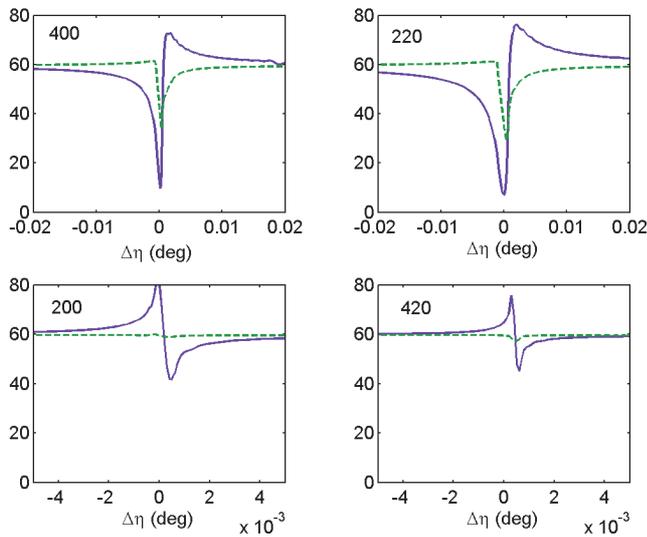


Fig. 2. The XRSW curves calculated in various GID diffractions for Mn lattice atoms (full) and randomly placed Mn atoms (dashed).

From the fits it follows that during the annealing, the relative density of randomly distributed Mn atoms with respect to Mn atoms in lattice and interstitial positions increased from 10^{-3} to $3 \cdot 10^{-3}$. This increase could be attributed to the growth of small MnAs clusters or to a gathering of the Mn atoms in a disturbed surface layer. A reliable explanation of this finding is not possible without additional experiments probing the positions of the Mn atoms close to the sample surface (using photoelectrons, for instance). This will be the subject of further investigations.

- [1] T. Dietl et al., *Science* **287**, 1019 (2000).
- [2] J. Sadowski et al., *Appl. Phys. Lett.* **78**, 3271 (2001).
- [3] G. M. Schott, et al., *Appl. Phys. Lett.* **79**, 1807 (2001).
- [4] J. Mašek, et al. *Phys. Rev. B* **67**, 153203 (2003).
- [5] L. X. Zhao et al., *Semicond. Sci. Technol.* **20**, 369 (2005).