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ESRF

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.

ESRF	**Experiment title:** In-situ anomalous diffraction study of the structural phase transitions in ferromagnetic GeMn layers	**Experiment number**: SI1916
Beamline: ID01	**Date of experiment**: from: 30. 9. 2009 to: 6. 10. 2009	**Date of report**: 8.2.2010
Shifts: 18	**Local contact(s)**: Gerardina Cabone	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

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Report:

One promising method for the production of semiconductors with a ferromagnetic ordering of spins at room temperature consists in the growth of composite structures containing small inclusions of ferromagnetic or superparamagnetic inclusions embedded in a diamagnetic semiconductor lattice. In our previous works [1,2,3] we have investigated the structure and magnetic properties of Mn-rich inclusions in GeMn epitaxial layers containing nominally few atomic percent of Mn. We found that, depending on the deposition temperature, either Mn-rich coherent clusters or Mn_5Ge_3 incoherent precipitates occur. Coherent clusters are created at lower growth temperatures (approx. at 60°C) and they exhibit a diamond-type lattice analogous to the Ge host lattice, the lattice parameter of which depends on the Mn content. Incoherent precipitates occur at higher growth temperatures (above 100°C) and their crystallographic Mn_5Ge_3 phase is hexagonal (space group P63/mcm (193)).

In our previous work [1] we demonstrated by grazing-incidence x-ray diffraction (GID) that the coherent inclusions deform the surrounding lattice in tension (i.e. the intrinsic parameter of the inclusion lattice is smaller than the Ge value), while the incoherent precipitates cause a negligible deformation of the surrounding lattice. The aim of this beamtime was to follow in situ the structure transformation of the coherent inclusions during a post-growth annealing. We expected that the coherent inclusions would transform to the Mn_5Ge_3 precipitates, this transformation should be clearly visible in GID reciprocal space maps taken in the $q_r q_a$ plane parallel to the sample surface.

We have measured the GID intensity diffracted from a series of GeMn layers with the Mn content ranging from 3% to 20% deposited at 60°C. The measurements have been carried out at room temperature and during annealing in vacuum at temperatures up to 600°C, using the photon energy of 6.5 keV (just below the MnK absorption edge), Figs. 1 (a,b) show representative examples of the intensity $q_r q_a$ maps measured before annealing (a) and during annealing at 400°C (b). The intensity map measured before annealing exhibits a typical shape; its asymmetry along the q_r-axis indicates that the inclusions deform the surrounding lattice in tension. In Fig. 1 (b) however, opposite q_r-asymmetry is obvious.

Possible explanation of this effect is based on the fact that the intensity scattered in a given point $\boldsymbol{q}$ of reciprocal space is a coherent superposition of two contributions. One component of the scattered wave is caused by the scattering from the deformed Ge lattice in the neighborhood of the inclusion and its amplitude

is proportional to the Fourier transformation of $\boldsymbol{h}.\boldsymbol{u}(\boldsymbol{r})$, where $\boldsymbol{h}$ is the diffraction vector and $\boldsymbol{u}(\boldsymbol{r})$ is the displacement vector around the inclusion (the Huang-scattering term). The other component of the scattered wave stems from the inclusion volume and it is proportional to $\Delta F_{\boldsymbol{h}}\Omega^{FT}(\boldsymbol{q})$, where $\Delta F_{\boldsymbol{h}}$ is the difference in the structure factors of the inclusion and the surrounding (proportional to the difference in electron densities) and $\Omega^{FT}(\boldsymbol{q})$ is the Fourier transformation of the shape function $\Omega(\boldsymbol{r})$ of the inclusion (unity in the inclusion and zero elsewhere). The q_r-asymmetry of the GID intensity map is then determined by the difference of phases of these two contributions. Therefore, the change in the q_r-asymmetry during annealing can be explained by the change in the sign of the displacement field $\boldsymbol{u}(\boldsymbol{r})$ or by the change in the sign of the density contrast $\Delta F_{\boldsymbol{h}}$. Both explanations can yield good fits and an additional piece of information is necessary to decide which explanation is correct. Recently, we are using another independent methods (transmission electron microscopy, among others) to solve this problem.

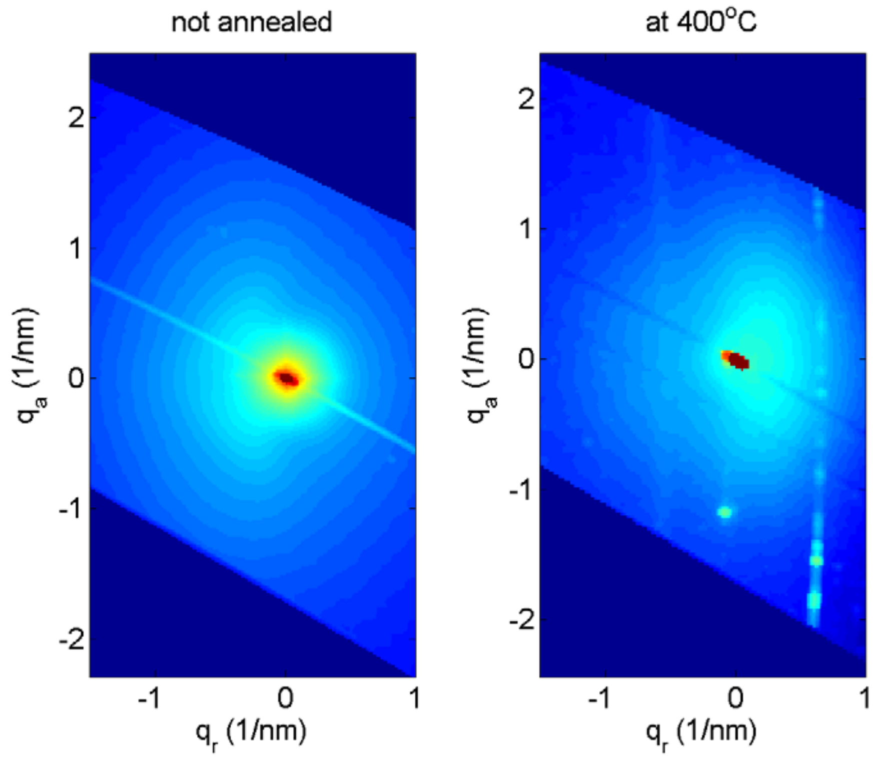

Fig. 1 Reciprocal-space map of diffracted intensity taken in grazing-incidence diffraction geometry in the $q_r q_a$ plane parallel to sample surface before annealing (left) and during annealing at 400°C (right). The Ge(Mn) layer contains nominally 3.4% Mn and it has been deposited at 60°C. The intensity distribution in the left panel is characteristic for coherent cubic inclusions. The vertical lines in the right panel are Debye rings caused by diffraction in the wall of the Be dome.

[1] V. Holý, R. T. Lechner, S. Ahlers, L. Horák, T. H. Metzger, A. Navarro-Quezada, A. Trampert, D. Bougeard, and G. Bauer, Phys. Rev. B **78**, 144401 (2008).
[2] R. T. Lechner, V. Holý, S. Ahlers, D. Bougeard, J. Stangl, A. Trampert, A. Navarro-Quezada, and G. Bauer, Appl. Phys. Lett. **95**, 023102 (2009).
[3] V. Holý, Experimental report SI-1467 (2008).