EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

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.

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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: Local control of magnetocrystalline anisotropy in (III,Mn)V dilute moment ferromagnetic semiconductor micro- and nano-devices	Experiment number: SI-1598
Beamline: ID-10B	**Date of experiment**: from: 13. 9. 2007 to: 18. 9. 2007	**Date of report**: 26.2.2008
Shifts: 15	**Local contact(s)**: Jiří Novák	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Prof. Dr. Vaclav HOLY
Dr. Tomas JUNGWIRTH
Ing. Vit NOVAK

Report:

(Ga,Mn)As and related ferromagnetic semiconductors are unique due to their dilute moment nature and the strong spin-orbit coupling [1,2]. Doped with only ~1-10\% of Mn magnetic moments, the saturation magnetization, M_s, and the magnetic dipole interaction fields are ~100-10 times weaker in these materials than in conventional ferromagnets. Recently it was demonstrated that it is possible to locally tune and control spin-orbit coupling induced magnetocrystalline anisotropies in (Ga,Mn)As [3-6] by lithographically producing strain relaxation.

The aim of the measurement was to determine the degree of lateral elastic relaxation in surface periodic gratings litographically patterned on GaMnAs layers, the grating period was 2 μm. We used grazing-incidence x-ray diffraction measured at the beamline ID10B, using the photon wavelength of 1.558 Å. The diffracted radiation was detected by a linear detector perpendicular to the sample surface; for the improvement of the angular resolution we used an analyzer crystal placed in front of the detector. We have investigated a series of 6 samples, having two different Mn concentrations 2% and 7%, various etching depths (from 180 nm to 1200 nm) and two orientations of the gratings ([110] and [100]). For each sample, we have measured reciprocal-space maps of diffracted intensity in vertical $q_r q_z$ and $q_a q_z$ planes. In both cases, the planes were perpendicular to the gratings. The $q_r q_z$ plane (radial plane) was parallel to the diffraction vector (040 for [100]-oriented gratings and -220 for [110]-oriented gratings), the $q_a q_z$ angular plane was perpendicular to the diffraction vector 400 or 220. The measurements have been carried out for two incidence angles of primary radiation, 0.3 deg and 0.4 deg, just below and above the critical angle of total external reflection. Because of the grating periodicity, the maps exhibits a sequence of tens of lateral satellites, the distance of which is inversely proportional to the grating period. Since the elastic relaxation in the grating occurs only in the plane perpendicular to the gratings, the angular intensity maps are sensitive only to the shape of the gratings and not to their strain status, while the radial maps are affected by the strain relaxation. In order to determine the strain relaxation, we used only the envelope curves of the satellites in the radial maps, since their shape is determined only by the resolution function of the experimental setup. From the measured maps we determined the q_r-integrated intensities of lateral satellites as functions of the vertical coordinate q_z. These integrated intensities were compared with numerical simulations; for the simulations we have used the shapes of the gratings determined from scanning electron microscopy and elastic displacement fields calculated numerically using a finite-element method.

The intensity simulations were carried out using the distorted-wave Born approximation. From the comparison of measured and simulated satellite intensities we have determined the relative mismatch f of the GaMnAs and GaAs crystal lattices. Figures 1a and 1b show two examples of measured and simulated satellite intensities.

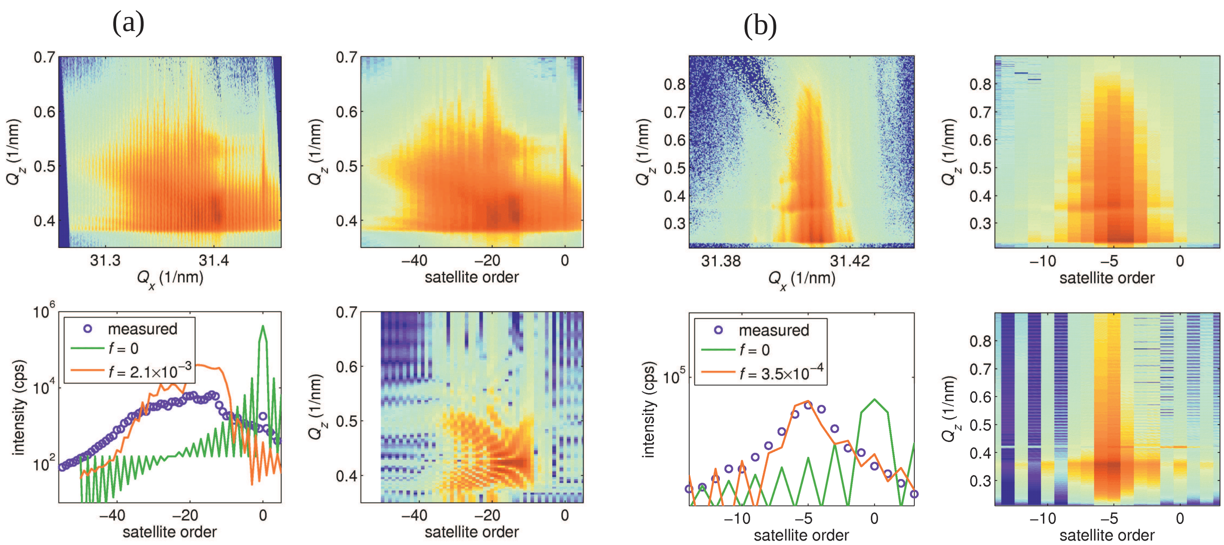

Fig. 1 Radial reciprocal-space maps of samples #1 (7% Mn, etching depth 180 nm – (a)) and #2 (2% Mn, etching depth 1250 nm – (b)), diffraction 040, incidence angle 0.3 deg. In each figure, the upper left panel is the measured reciprocal-space map in the radial plane, the upper right panel shows the integrated intensities of lateral satellites, the simulated integrated intensities are in the lower right panel. The lower left panel compares the measured and simulated intensities of lateral satellites doubly-integrated (over q_r and q_z). The values of the mismatch f resulting from the fits are indicated.

The elastic displacement fields used for the intensity simulations are plotted in Fig. 2. In the grazing-incindence geometry, only the horizontal displacement component parallel to the mean sample surface and to the diffraction vector is important. Since the displacement field scales with the mismatch f, the finite-element simulation was performed only for a single value of f and the measured intensities were fitted to the simulations using f as a single fitting parameter. The measured and simulated integrated intensities of the lateral satellites compare quite well. The measurements of the elastic relaxations will be compared with the SQUID magnetometry results determining the magnetocrystalline anisotropy in etched gratings.

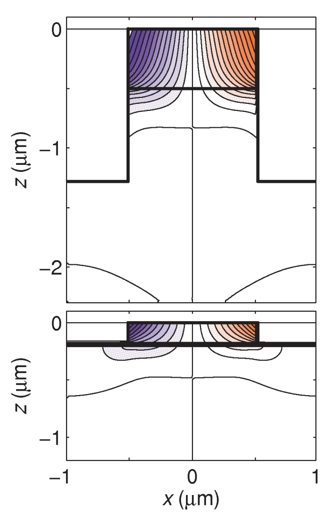

Fig. 2. Horizontal displacements in a single grating calculated by a finite-element method for the lattice mismatch $f = 0.01$ sample #2 (upper panel) and #1 (lower panel). The contour step is 0.05 nm.

References

[1] F. Matsukura, H. Ohno, and T. Dietl, in *Handbook of Magnetic Materials*, edited by K. H. J. Buschow (Elsevier, Amsterdam, 2002), vol. 14, p. 1.

[2] T. Jungwirth, J. Sinova, J. Mašek, J. Kučera, and A. H. MacDonald, Rev. Mod. Phys. **78**, 809 (2006).

[3] J. Wunderlich, A. C. Irvine, J. Zemen, V. Holý, A. W. Rushforth, E. D. Ranieri, U. Rana, K. Výborný, J. Sinova, C. T. Foxon, et al., Phys. Rev. B **76**, 054424 (2007).

[4] S. Hümpfner, M. Sawicki, K. Pappert, J. Wenisch, K. Brunner, C. Gould, G. Schmidt, T. Dietl, and L. W. Molenkamp (2006), cond-mat/0612439.

[5] K. Pappert, S. Hümpfner, C. Gould, J. Wenisch, K. Brunner, G. Schmidt, and L. W. Molenkamp (2007), cond-mat/0701478.

[6] J. Wenisch, C. Gould, L. Ebel, J. Storz, K. Pappert, M. J. Schmidt, C. Kumpf, G. Schmidt, K. Brunner, and L. W. Molenkamp (2007), cond-mat/0701479.