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ESRF

Experiment Report Form

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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;
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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:** Study of the early stages of the spontaneous lateral modulation in short-period superlattices	**Experiment number**: SI993
Beamline: ID01	**Date of experiment**: from: 21.04.2004 to: 26.04.2004	**Date of report**: 17.02.2005
Shifts: 15	**Local contact(s)**: Dr. Baerbel Krause	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

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Dr. Andrew Norman, National Renewable Energy Laboratory, Golden CO, USA

Report:

During epitaxial growth of short-periodic InAs/AlAs superlattices nearly strain-matched to the InP substrate, a spontaneous lateral modulation of the thicknesses of individual layers is observed. In a series of papers [1-3], the dependence of the direction of the spontaneous modulation on the average strain in the superlattice was studied by means of transmission electron microscopy. It has been found that in superlattices under global compression (more InAs), [100] and [010] modulation directions occur, while [130] and [310] directions can be found in superlattices under global tension (more AlAs).

In [4] we have used grazing-incidence diffraction (GID), grazing-incidence small-angle scattering (GISAXS) and coplanar diffraction (XRD) at two different energies for a detailed study of the spontaneous modulation process. From a fit of the measured data with numerical simulation of diffuse scattering we could obtain a profile of lateral modulation. We have demonstrated that the modulation is caused by a partial bunching of monolayer steps during epitaxial growth.

In the present beamtime, we have studied the onset of the modulation process, i.e., the dependence of the modulation amplitude on the number of bilayers in a superlattice under global compression (modulation direction [100]). For this purpose, we have measured a series of GID reciprocal space maps in two diffractions 400 and 040 in reciprocal planes parallel to the sample surface. We used the wavelength 1.5468 Å, the incidence angle 0.27° was chosen just below the critical angle of total external diffraction (0.28°). The diffracted beam has been detected by a linear position-sensitive detector mounted perpendicularly to the sample; the detector covered the range of the exit angles from 0 to 1°.

A series of samples was investigated with the numbers of superlattice periods 0, 1, 2, 5, 10 and 20. Figure 1 shows the measured GID maps in diffraction 400 of the samples with 2, 5, 10, 20 periods, the other samples do not exhibit diffuse scattering at all. In the measured maps, lateral satellites are visible stemming from the thickness modulation. The modulation direction differs from [100] by about 15°. Similar maps were obtained in diffraction 400; from these maps the modulation direction close to [010] follows.

periodic modulation of the lateral strain, the lateral modulation of chemical composition (i.e., the modulation of the structure factor) plays a minor role. Since the periodic displacement $\boldsymbol{u}(\boldsymbol{r})$ occurs in the formulas for the scattered intensity only in the dot product $\boldsymbol{u}(\boldsymbol{r}).\boldsymbol{h}$ with the diffraction vector $\boldsymbol{h}$, the modulation in the direction nearly perpendicular to $\boldsymbol{h}$ does not cause lateral satellites. Therefore, combining the results of 400 and 040 diffraction we find that both modulation directions close to [100] and [010] are simultaneously present in our samples.

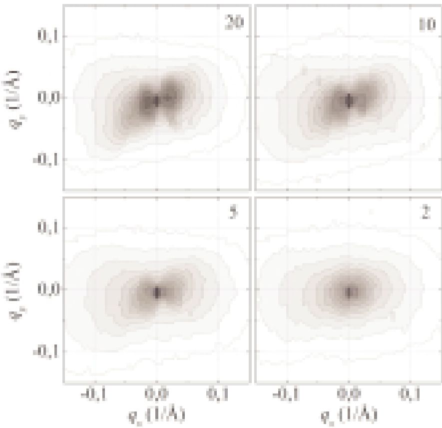

Fig. 1. GID reciprocal space maps measured in the plane $q_x q_y$ parallel to the sample surface. The diffraction vector 400 is parallel to the q_x axis, the numbers of periods off the superlattice are given in the right corners of the panels.

The degree of spontaneous modulation can be estimated from the width of the intensity satellites. In Fig. 2 we have plotted linear scans extracted from the measured maps crossing the lateral satellites.

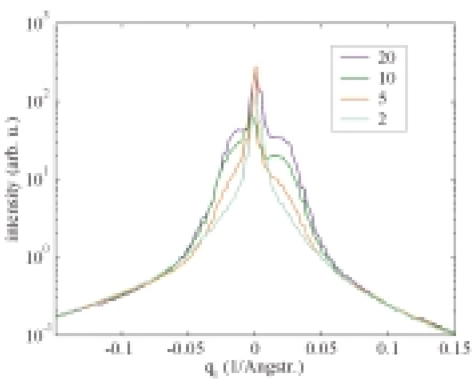

Fig. 2. Linear scans extracted from the reciprocal space maps in Fig. 1 across the lateral satellites, various numbers of superlattice periods.

From this figure an asymmetry of the linear scans is obvious. This asymmetry stems from the interference of the wave scattered from the displacement field with a wave scattered from the density modulations [5]. The height of the satellites is proportional to the modulation amplitude, while the satellite width depends on the degree of periodicity of the spontaneous modulations. From Fig. 2 it follows that the amplitude of the modulation increases with the number of superlattice bilayers, while the degree of periodicity of the modulation is nearly independent on this number. Both parameters can be determined by a fitting of the linear scans to a suitable theoretical model. This will be the subject of a publication that is still under preparation.

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[5] U. Pietsch, V. Holý and T. Baumbach, *High-Resolution X-Ray Scattering From Thin Films to Lateral Nanostructures*, Springer-Verlag Berlin, Heidelberg, New York 2004.