ESRF	**Experiment title:** Characterization of semiconductor laser gratings by means of high resolution diffraction	**Experiment number**: HS-723
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Report:

We have investigated a set of one-dimensional semiconductor grating structures (surface gratings and buried gratings) with a typical lateral period of about 250 nm. These samples were prepared by holographic and electron beam lithography. The aim of our study was to quantitatively characterize the quality of the lithography process along and perpendicular to the grating lines. In the perpendicular direction deviations from the exact lateral periodicity may occur, whereas along the gratings thickness variations or a curvature of the grating lines may be present. Both effects may be expressed by respective correlation lengths along both directions.

In order to receive appropriate information we have performed grazing incidence small angle x-ray scattering (GISAXS) with the use of a low background CCD-detector (SMART from Bruker-AXS) that is available at ID11. We use the CCD detector in such a way that different channels (pixel) of the CCD correspond to different in-plane and out-of-plane scattering angles. In order to achieve the required resolution the incident beam width at the sample was reduced to 30 μm x 30 μm (focused beam) and the detector was placed 4 m behind the sample. The entire beam path between sample and detector was evacuated. By tuning the angle of incidence α_i with respect to the sample surface (typically in the range 0°..1°) a complete three dimensional mapping in the vicinity of the 000 reciprocal lattice point can be performed. The very intense specular beam and the (00) truncation rod have been attenuated by an absorbing wire that was placed in front of the detector.

Due to the high brilliance at ID 11 and the use of the CCD detector the experimental conditions have been excellent. The x-ray beam has been focused on the sample. By using 2x2 binning and off-line integration of typically 30 CCD-frames a dynamic range of 10^5 has been achieved (for the diffuse intensity) in a CCD picture. A typical GISAXS picture of a surface grating that has been accumulated for 30 seconds (!) is shown in Fig. 1. The vertical streaks (rods) are due to the lateral periodicity of the grating. They are surrounded by diffuse scattering originating from structural imperfectness of the grating and from the surface roughness. It is not clear for which reason the region below the sample surface horizon (horizontal line that lies approximately in the middle of Fig.1) shows this modulation too.

The data evaluation revealed some difficulties mainly due to the fact that the software (licence by Bruker-AXS) that is necessary for processing the raw data is available at the experimental station at ESRF only. Therefore, appropriate computer programs that are able to handle the huge data arrays had to be developed. As a result of these developments we are able to generate 2D cuts as well as ‘flights’ through reciprocal space along certain directions.

In order to evaluate the lateral correlation lengths along and perpendicular to the grating structure a two dimensional in-plane cut through the entire 3D map has been extracted (Fig. 2). The sample surface normal is parallel to q_z with the grating lines collinear with q_x. For a perfect grating a set of narrow peaks aligned along q_y is expected. Obviously, this is not exactly fulfilled, since the peak positions follow a curved line. We are presently evaluating possible reasons for the image distortion.

However, quantitative values for the lateral correlation lengths can be extracted. The correlation length of the grating perpendicular to its lines, ξ_y, is rather large. It is limited by the experimental resolution, and we may estimate the correlation to be larger than ξ_y = 20 µm. Along the lines the correlation length for the grating of Fig.2 is ξ_x = 6 µm. This value is not limited by the experimental resolution which is better than $\Delta q_x = 2\cdot 10^{-4}$ nm^{-1} in q_x direction. From experiments with planar layers we expect that an additional typical length scale (correlation length) may be present. It characterizes the lateral surface roughness and is, however, smaller.

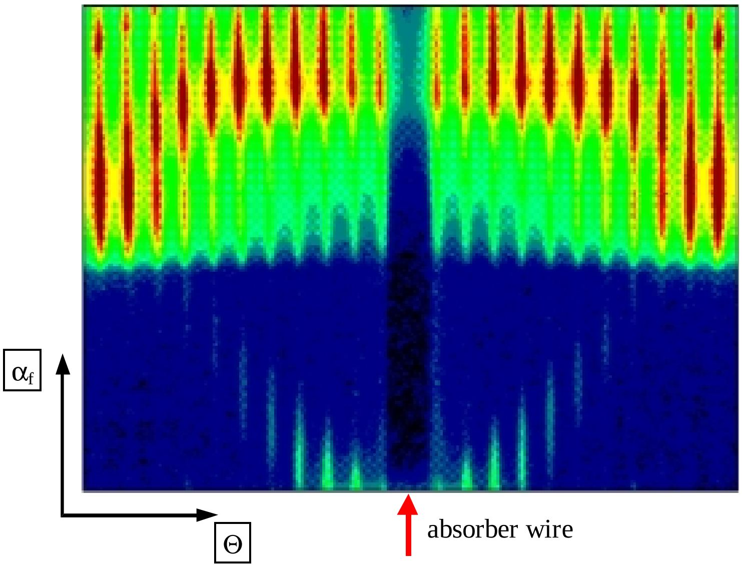

Fig. 1: CCD raw data (GISAXS) for a InP surface grating (9660 eV, α_i = 0.46°).Vertical intensity streaks are satellites originating from the lateral grating periodicity. The image shows an accumulation of 30 frames, 1 sec. exposure time each.

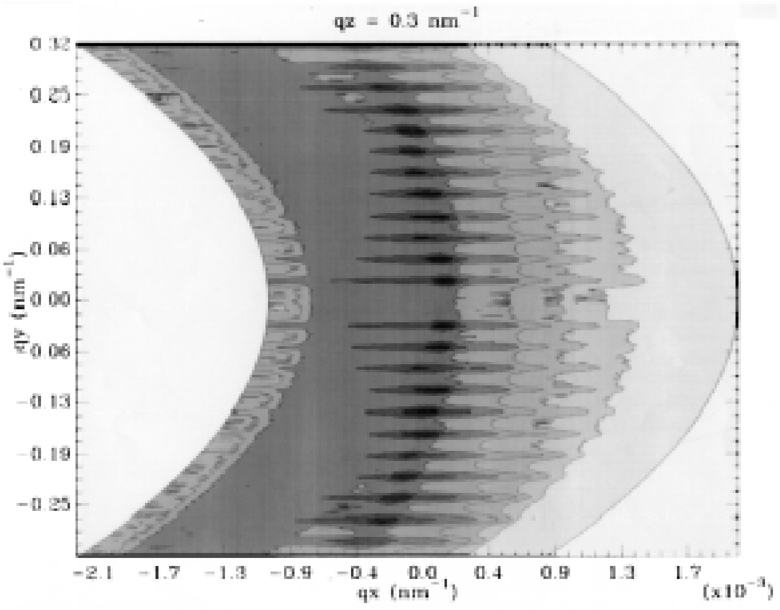

Fig. 2: In-plane intensity distribution at q_z = 0.3 nm^{-1} (integrated over a q_z range of 0.01 nm^{-1}). The picture is calculated from 32 images like fig. 1. The lines of the grating are aligned along q_x. The grayscale is logarithmic with factors of 3. In q_x direction the halfwidth of the satellites is about Δq_x = 10^{-3} nm^{-1}. From this value a correlation length of about ξ_x = 6 µm can be evaluated.