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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 via the User Portal:

https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Reports supporting requests for additional beam time

Reports can 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:** Evaluation of CD-SAXS for roughness analysis in lines gratings	**Experiment number**: 32-02-806
Beamline: BM32	**Date of experiment**: from: 10/20/17 to: 10/24/17	**Date of report**:
Shifts: 15	**Local contact(s)**: Jean-Sébastien Micha, Samuel Tardif	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

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Report:

Characterisation of line roughness is a big challenge in microelectronic. In particular, the lateral roughness of lines is quite complex to extract with current method like AFM or SEM. The use of SAXS in transmission mode can be an answer with a high resolution expected. The main goal of this experiment is to evaluate the capability of SAXS for measuring lateral roughness of lines.

For this first experiment we decided to prepare lines grating in cleanroom with controlled roughness (Figure 1). It means that the amplitude and periodicity of the lateral roughness is defined a priori by the lithographic process. For periodic roughness, different type of roughness (LER, LWR, ALWR) have been prepared. For all the analyzed samples during this run, the roughness frequency is monomodal, for simplicty of data treatment.

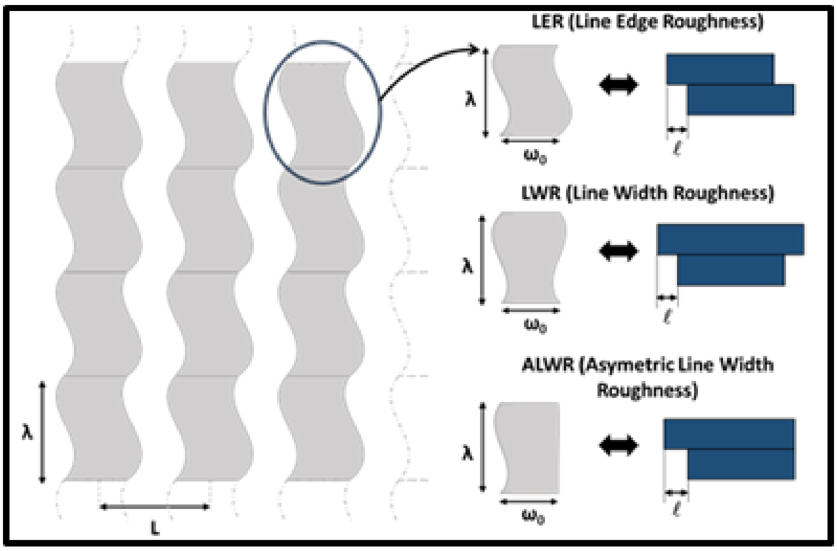

Figure 1: Lines gratings with roughness type description (LER, LWR, ALWR)

During the allocated beam time, three type of measurements have been performed: i) we first measured a 2D image of the line gratings scattering; ii) we measured using a punctual detector the line profile of different orders of diffraction transverse to the lines and parallel to the lines, and iii) we measured also these peak profiles at different tilts Ω of the samples (see figure 2). From these measurements, we could extract the pitch of the grating, the shape and width of the lines, but also the roughness period and the roughness amplitude.

We first measured a sample without programmed roughness. This sample can be considered as a reference when correlating with the others samples. Two kind of roughness named "LWR" and "ALWR" where measured at different amplitudes.

Each sample has been finely aligned on the BM32 goniometer. In particular we took attention to the alignment of the patterned area on the rotation axis, since the lines grating area measure only 250x250µm². Moreover, as we used punctual acquisition, it was important to check that the lines were completely horizontal in order to measure accurately the diffracted intensities.

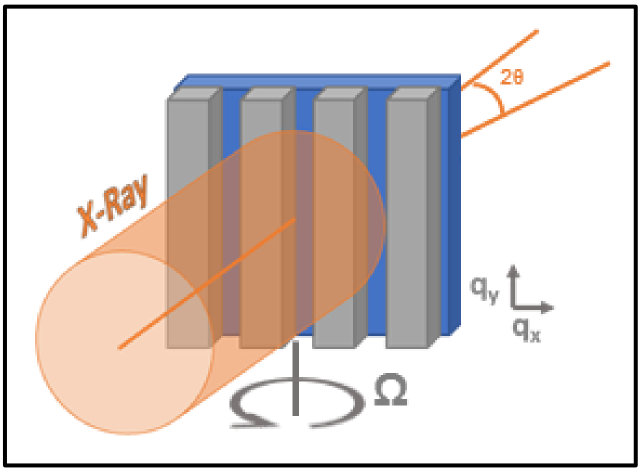

Figure 2 : Scheme of the experiment with definition of rotation Ω

The figure 3 shows a typical 2D images of a line gratings with controlled roughness. Spots along the q_x axis are related in position to the pitch and in relative intensity to the line width. The spots along the q_y axis are related to the lateral roughness of the lines. As for the equatorial spots, the positions and relative intensities of these spots give access to the roughness period and to the roughness amplitude.

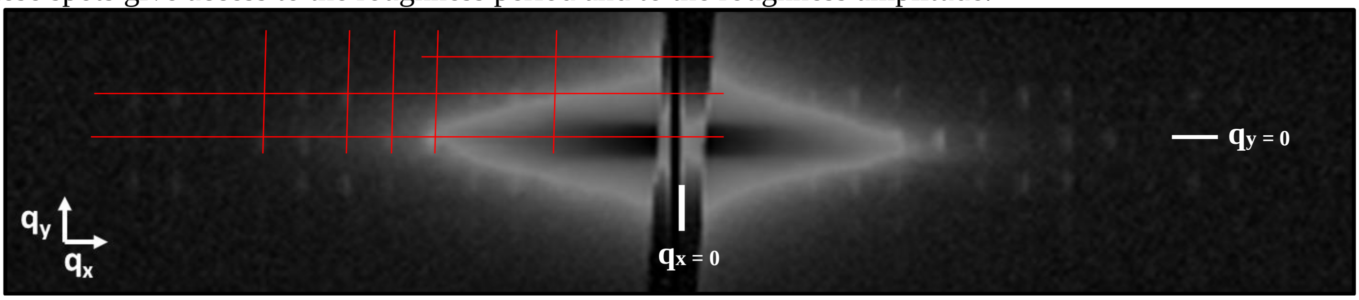

Figure 3: Diffraction pattern of a sample with controlled roughness, in red we show the few cuts measured with the punctual detector
(q_y=0, first and second roughness diffraction order; q_x= 3, 6, 7, 8 and 10 diffraction order)

In a first analysis of these images, we can extract already the pitch of the gratings. Using the measurements at different Ω values, we can also extract the shape of the lines. Thanks to the q_x measurements at $q_y = 0$, for our reference sample, we obtain the following values: a pitch =199.3nm, line height = 98.0nm, CD_{line} = 42.0 nm and β =-2.10°. First, parameter was calculated directly with a peak fitting and the relation: $L = \frac{2\pi}{q_x n}$. For the other parameters we used our own analysis software with a reverse problem solving.

With these different measurements we could also study the impact of roughness amplitude on intensity of diffraction. For instance, the figure 4 shows the third diffraction order along q_x, measured on samples with ALWR type of roughness and several roughness amplitudes. The relative decrease in intensity between the two peaks is clearly related to the roughness amplitude as reported in figure 5. We conclude that we could extract roughness information with a sub-nm resolution.

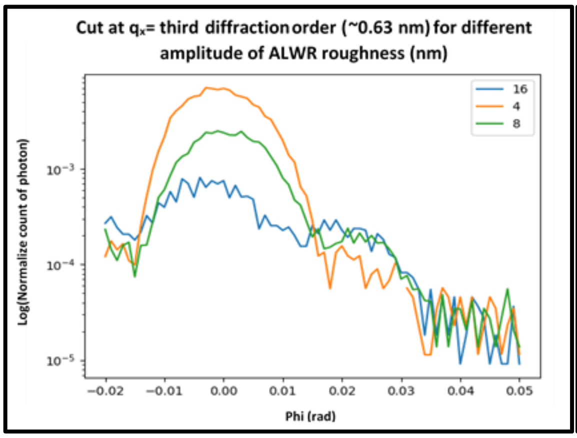

Figure 4 : q_y cut at the third order of diffarction along qx

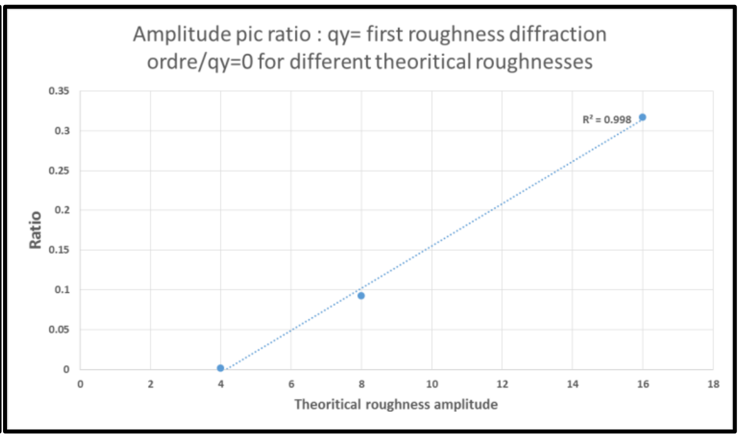

Figure 5 : Relationship between peak intensity ratio and roughness amplitude

This experiment also confirms that we can distinguish LER and LWR type of roughness thanks to the form factor impact. For instance in case of LER, the minima of intensity are aligned on q_y as showed in our simulations.

All the measurements are still under treatment and a publication at the SPIE conference dedicated to CD analysis is expected in beginning of 2018.

For the next step of this study we have prepared new samples with a roughness closer to the "natural" roughness created by the lithographic process, i.e. with multiple periods, variable amplitudes as described by autocorrelation function and spectral density. We have also reduced locally (under the patterned area) the Si substrate thickness in order to obtain a better contrast.