

## Wavefront measurements by means of X-ray grating interferometry

The unique properties of the X-ray pulses delivered by the SPring-8 Angstrom Compact free electron Laser (SACLA) in terms of photon flux, pulse duration and spatial coherence initiated novel and innovative experiments. Many of these depend on a clean and well-defined wavefront or phase. The conservation of the latter property is, however, one of the most demanding challenges in the design of X-ray beamlines and instrumentation components despite recent progresses. Thus, adequate metrology tools are required to characterize the wavefront under operational conditions in order to support experiments and improvements of the optical components.

In this respect, it was demonstrated that X-ray grating interferometry (XGI) is a valuable technique for spatially resolved *in situ* investigations of the X-ray wavefront at synchrotron beamlines [1] and at hard XFEL facilities [2]. With respect to off-line metrology tools, XGI allows for an at-wavelength characterization of the optical components and to identify in a non-invasive manner eventual radiation related deteriorations of the wavefront properties. We employed the XGI technique, which offers an angular sensitivity of the order of ten nanoradian, to investigate the X-ray wavefront after the optical elements, a pair of total reflection mirrors (TRM) or a Si (111) double crystal monochromator (DCM) [3], installed at beamline **BL3** of SACLA [4].

The principle of XGI is based on the Talbot effect: following the diffraction by a periodic binary grating on which the X-rays are incident, the propagation direction is changed by a small shear angle and at certain, discrete distances downstream of the diffraction grating a constructive interference pattern is created. Any distortion in the wavefront will induce a distortion in the measured interference pattern. The angular sensitivity of the grating interferometer depends on the distance behind the grating at which the interference pattern is measured and inversely on the period of the binary grating. The latter parameter determines also the period of the diffraction pattern which can, given the micro-sized structure of the diffraction grating, not be resolved by position-sensitive detectors. Therefore a second grating, having a period matching the one of the interference pattern, is inserted in front of the detector and used as a transmission mask (Fig. 1), resulting in the creation a pattern of moiré fringes which can be conveniently detected in a single-shot mode.

The employed gratings (Fig. 2) were produced

from thinned Si substrates using electron-beam lithography and deep reactive ion etching. The diffraction grating, having a period of 4  $\mu\text{m}$ , was designed to induce a  $\pi$ -phase shift of the X-ray photons passing through the grating structures and to provide an optimum diffraction efficiency into the  $\pm 1^{\text{st}}$  diffraction order. The trenches of the second grating, called absorption grating and having a period of 2  $\mu\text{m}$ , were filled with gold, deposited by electroplating, in order to absorb most of the incident photons and optimize the fringe contrast and visibility. It is important that the used gratings are free of any distortions and defects as these would deteriorate the quality of the measurement and of the extracted results. The grating interferometer was positioned in the experimental hutch 1 at a distance between 12.2 m and 17.2 m downstream of the different optical beamline components and operated in the 11<sup>th</sup> fractional Talbot order (integrating distance of 220.4 mm for a photon energy of 12.4 keV). The moiré patterns were recorded by a 2D camera system coupled to a YAG screen (effective pixel size of 3.83  $\mu\text{m}$ ).

Following a calibration measurement, required for a quantitative analysis, the spatially resolved fringe phase and wavefront propagation angles at the interferometer are extracted from the single-shot moiré fringe patterns through Fourier analysis [5]. Subsequently the equivalent height profile of the investigated optical components in the direction perpendicular to the grating structures is obtained. While the wavefront distortions induced by the optical components are retrieved by taking into account the expected spherical wavefront shape, the individual contributions of the mirrors, respectively the crystals, cannot be separated.

The wavefront aberrations were found to be characterized by a root-mean-square value of

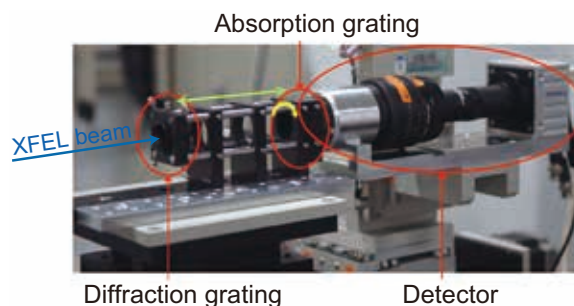


Fig. 1. Picture of the grating interferometry setup.

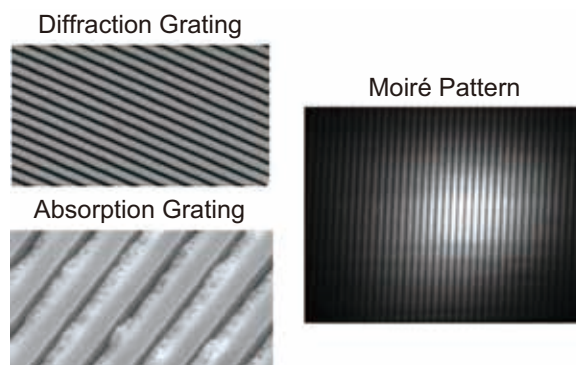


Fig. 2. Scanning electron micrographs of the used grating and example of a recorded moiré pattern.

0.17  $\mu\text{rad}$  or better while the retrieved combined height profiles showed that the installed optical components are of excellent quality [4] (Fig. 3). The differences on the horizontal scale in Fig. 3 are due to different incidence angles of the XFEL beam on the optics. Only at the edges of the mirrors a more pronounced deformation was observed which might be attributed to the mirror mounting. This observation emphasizes the importance of *in situ* measurements

under operational conditions. Moreover, the results confirmed and validated the sensitivity of XGI and its potential as a metrology tool. Indeed, the investigated TRM are among the best currently available mirror (sub-nanometer height variation for an individual mirror). The presented experiment demonstrated thus the potential of XGI to support and contribute to further developments in mirror manufacturing and mirror mounting.

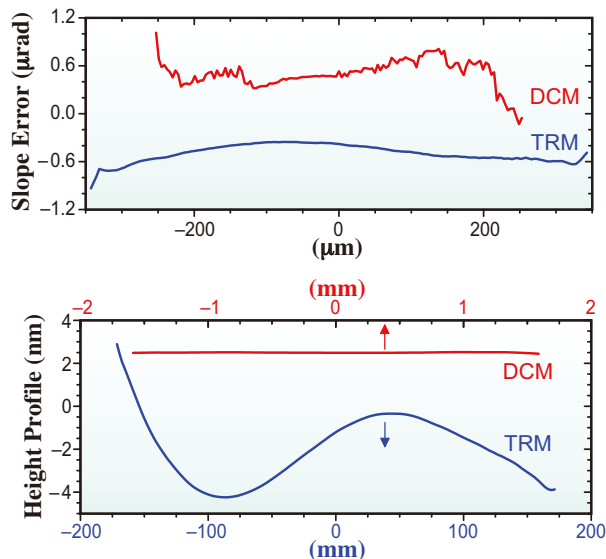


Fig. 3. Aspherical component of the wavefront slope and height profile of the TRM and the DCM extracted from the averaged moiré patterns recorded at an energy of 12.4 keV.

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## References

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