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Robust Ptychographic X-ray Speckle Tracking with Multilayer Laue lenses

With the development of more intense and coherent X-ray sources there is an ongoing drive to design and develop better X-ray focusing optics, which could focus X-ray beams down to about 1 nanometer [1]. Such optics would have a major impact in the field of X-ray microscopy and various modalities of X-ray imaging that investigate nanostructured materials and biological samples in-situ and in-operando or where extremely high X-ray intensities are required [2, 3]. However, diffraction limited X-ray optics are very challenging to make and the achievable resolution is mainly limited by optical aberrations. Thus, there is an increasing need for at-wavelength and in-situ wavefront metrology techniques, which are sensitive enough to yield accurate wavefront measurements. For us, high numerical aperture (NA) multilayer Laue lenses (MLLs) are of particular interest. We are developing these type of lenses in our laboratory and in order to make steady improvements it is critical to characterise their performance as soon as they are prepared. For this purpose we are using wavefront sensing technique that works with low brilliance and low coherence lab-based X-ray sources.

Ptychographic X-ray speckle tracking (PXST) [4] meets the aforementioned requirements. In a PXST setup an object is placed in the divergent X-ray beam produced by an MLL lens at a fixed distance from the sample. The object creates a speckle pattern on the detector and as one scans the sample across the beam, the speckles shift on the detector from one frame to another. By tracking deviations of the shifts of the speckle pattern one can obtain the phase gradient of the X-ray wavefront. This can be integrated to obtain the wavefront of the incoming X-ray beam. The advantage of the PXST method is that it offers a high angular sensitivity but at the same time has low requirements on transverse and longitudinal coherence of the X-ray beam. Moreover, it alleviates the problem of measuring the unaberrated sample profile (reference image). Instead, the virtual reference image can be reconstructed from collected holograms with a nanometer precision as long as there is sufficient overlap of the illuminated regions of the sample. This feature enables characterisation of highly divergent wavefields produced by high NA X-ray optics, such as MLLs.

In this poster we present an improved version of this technique, which we call robust ptychographic X-ray speckle technique (R-PXST). R-PXST is based on PXST. It is being used not only to determine the wavefront aberrations of MLLs but also to obtain unaberrated images of nanostructured samples with high resolution. Some examples obtained with our setup at P11 beamline (PETRA III synchrotron) will be shown. We find that due to the non-parametric regression techniques used in the reference image reconstruction together with the Huber regression employed in the lens aberration update procedure, our R-PXST technique is applicable to a wider range of experimental parameters than PXST and is also highly robust against the noise in the intensity measurements.

References:

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