At-wavelength metrology of X-ray beams and optics using random modulation

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Speckle is one of the very first phenomenon that intrigued scientists when lasers and other powerful coherent light sources became available. Indeed, arising from interference effects from any small object, defect or dust located in the beam path, these random intensity modulations, whose contrast ratio can reach 100%, is often seen as a nuisance from an optical point of view. Notwithstanding that speckle can be considered as noise, it also features some properties that can be exploited for metrology and imaging purposes. This is especially true with visible light where many optical techniques make good use of speckle in a variety of configurations, such as in transmission or reflection in material, with static or dynamic objects under investigation, etc.

Within the X-ray regime, for a very long time the term speckle referred to the pattern obtained upon x-ray diffraction of a coherent beam from a sample. More recently, speckle could be observed and described in the bright field when illuminating an object containing small structures with a synchrotron coherent beam. Such X-ray near field speckle was shown to possess properties of interest for both metrology and ultra-small angle X-ray scattering measurements. One interesting property of the X-ray near field speckle is that its distortion upon propagation is solely ruled by the wavefront shape. Thus, a few approaches were developed in order to sense the phase of a beam by modulation with a random phase object placed along the X-ray path. Using the speckle grains as markers on an imaging detector, the derivative of the phase can be recovered through the intensive use of numerical correlation algorithms.

Today, X-ray speckle-based metrology and imaging are a collection of data and processing methods which permit, from a very simple setup, to derive a wavefront with a nanoradian order accuracy and a micrometer spatial resolution. The approaches have low requirements on the transverse and longitudinal coherence lengths. Depending on the number of images, the type of scan and the setup geometry, different sensitivity and resolution combinations are achievable.

This presentation will review various data collection schemes, their associated processing, and will emphasize the differences between them. We underline both their advantages and drawbacks and provide guidelines on the parameters to be considered with respect to the type of metrology and beam characterization envisaged.

The techniques' applications will be illustrated with examples of metrology characterizations of lenses and reflective optics. I will be showing how the technique sensitivity can be used to explain some interference effects and relate them to the transfer of intensity equation.

To conclude I will describe successful implementations of the methods at a variety of X-ray sources, including synchrotrons, X-ray Free electron lasers, micro-focus and laser based sources.