Coherent hard X-ray microscopy for the characterization of mesoscopic materials

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We present a coherent high energy X-ray microscope to study the wide range of natural and artificial mesoscopic materials that are structured on scales of the order of a few to a a few hundred nanometers. The concept of the proposed microscope is based on employing compound refractive lenses allowing to retrieve high resolution diffraction pattern and real-space images in the same experimental setup [1-4]. This idea, well-known for the studies of crystals by high resolution transmission electron microscopy, is the key ingredient of our approach.

The microscope operates under a coherent illumination where a diffraction pattern of the specimen is formed in the back focal plane of the condenser and an inverted two-dimensional image of the object is formed by objective lens in the image plane [5]. The diffraction mode is used to investigate the structure over the macroscopic distances and to orient the crystals parallel to the low index direction to perform high-resolution imaging on the local scale. The image formation relies on phase contrast due to the interference of several diffracted beams [6]. A high spatial coherence is needed in the imaging mode to ensure a reasonable contrast. The coherence in terms of the angular source size determines the lens angular resolution (< 1μrad) to get high resolution diffraction patterns.

Functioning at 10 – 30 keV, the microscope is one of the brunches of the multimodal instrument which is under the development at the ID06 ESRF beamline. It consists of the condenser, the objective lens and two X-ray CCD cameras – large area detector for diffraction and high resolution CCD for imaging. Condenser and objective assemblies are comprised of Be parabolic refractive lenses. Switching from the diffraction mode to the imaging is achieved by placing the objective lens into the beam, and the chosen detector. The tunable objective lens offers full-field imaging with variable resolution and field of view. It allows for the identification of features of interest in a coarse resolution overview before increasing magnification to study these features with maximum resolution. At present, at the maximum magnification a resolution of 100 nm is achieved, but it should be noted that the studies on its improvement are curred out and in the near future we can expect resolution about 30 nm.

The microscope was applied for study of natural and synthetic opals, metal inverted photonic crystals and colloidal suspensions [5,7]. The combination of the direct-space imaging and high resolution diffraction provide a wealth of information on their local structure and the long range periodic order. The concept of the hard x-ray microscope emerged concomitantly with the realization that the ESRF source upgrade would, through the greatly enhanced brilliance and fraction of coherent light, open entirely new frontiers in materials imaging [8]. Short acquisition times with modern area detectors allow to extend the microscope to time-resolved studies of the crystallization dynamics, response of the mesoscopic structures to external stimuli such as mechanical strain, temperature jump or temperature gradient as well as external fields.

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