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Book of Abstracts

COHERENT DIFFRACTION IMAGING: TOWARDS SINGLE PARTICLE IMAGING USING FREE ELECTRON LASERS

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ABSTRACT

Structure determination has played a crucial role in fields ranging from physics, chemistry to biology. However, obtaining a full three-dimensional structure of an object can be extremely challenging. In particular, for nano-materials where the properties become strongly dependent on spatial arrangements of specific structures rather than the average atomic structure, this requires imaging information about spatial structural arrangements at larger length scales:

X-ray crystallography can reveal the globally averaged 3D atomic structures, based on the diffraction phenomenon but requires crystals. In fact, imaging of non-crystalline objects with X-rays is very appealing but it is limited due to the lack of suitable lenses to obtain resolution beyond several tens of nm. This limitation can be overcome by lensless X-ray imaging approach, called coherent diffraction imaging, where the X-ray optical systems are 'replaced' by computer algorithms. In contrast to the scattering produced with incoherent X-rays, the coherent pattern contains not only information about the amplitude of the scattered radiation, but also information about the phase of that radiation. The principle is illustrated in Fig. 1. Coherent X-rays illuminate a non-crystalline specimen producing a continuous diffraction pattern recorded by a pixel array detector, which has high quantum efficiency and dynamic range. The phases are uniquely encoded in such coherent diffraction pattern and when it is sampled at spacing sufficiently smaller than the inverse of the sample size, the phase information can be directly retrieved by using an iterative process [1]. The potential of coherent X-ray diffraction microscopy is enormous: the phase information contained in the diffraction pattern allows e.g. mapping of strains, whenever atoms are displaced from a lattice site due to defects, dislocations and deformations, morphology evolution of non-periodic systems etc. This was demonstrated experimentally using the x-rays from the 3rd generation synchrotron facilities for the first time in1999 [2] and has already been applied to investigate a wide range of materials, including semiconductors, magnetic materials, nano- and bio-systems [3 - 5].

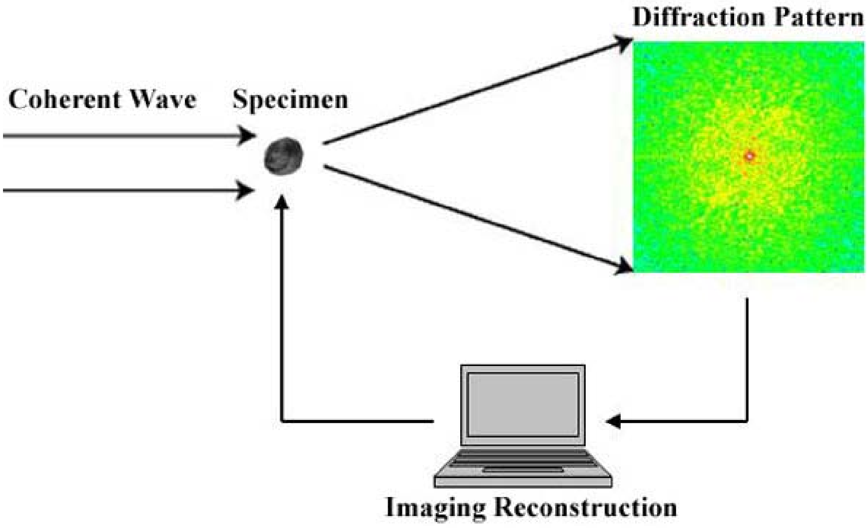

Fig. 1. Principle of coherent (lensless) imaging.

However, to reach diffraction-limited resolution requires very high flux of coherent X-rays, which is becoming available with the emerging Free Electron Laser facilities. Theory predicts that the extremely bright, ultra-short FEL pulses open new horizons for coherent imaging of non-periodic nano-scale objects, e.g. a single diffraction pattern may be recorded from a large macromolecule, a virus or a cell before the sample explodes and turns into a plasma [6, 7]. Such single-shot imaging offers also the possibility to study dynamic processes, e.g. the response of biological and chemical samples (cell-type structures, bio-implants, drug-delivery materials, polymers) to external electric fields, electronic excitations by a pump-laser as well as mechanical disturbance. These concepts have already been under validation with the single shot imaging experiments explored at FLASH in Hamburg and similar experiments are planned for FERMI@ELETTRA.

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