Diffraction Imaging at Synchrotron Light Sources: From Topography to Coherent Nanoprobes

Tobias Schülli[1]

[1] *ESRF, Grenoble France*

Presentation type: Tutorial Lecture **Presentation time:** 14:00-15:00

Diffraction imaging — the class of techniques that combines the structural sensitivity of X-ray diffraction with spatially resolved measurement — has undergone a profound transformation over the past three decades. What began with X-ray topography, a near-field technique exploiting the direct projection of diffraction contrast onto a detector or a film placed close to the sample, has evolved into a rich family of far-field methods that extract structural information from the angular distribution of scattered intensity.

This tutorial introduces the conceptual foundations of diffraction imaging and traces a path from the very idea to most advanced implementations. We begin with X-ray topography as a reference point: a technique requiring no focusing optics, exploiting near-field geometry defects across large crystal volumes with sensitivity to individual dislocations. Its simplicity, directness, and continued relevance at modern synchrotron sources make it the natural starting point for understanding what diffraction imaging fundamentally achieves.

We then examine how the transition to far-field geometry — where the detector records the full diffraction pattern rather than a direct image — opens access to a qualitatively different regime of information. Using X-ray optics, scanning nanobeam X-ray diffraction is a prominent and widely established example. Its full-field counterpart places the optics in the diffracted beam and is referred to as Dark Field X-ray Microscopy (DFXM). Both techniques see a rapid pick-up by different user communities and examples show their relevance in areas ranging from semiconductors to metallurgy.

As the far-field encodes phase as well as amplitude, the family of diffraction imaging methods is completed by Bragg Coherent Diffraction Imaging (BCDI) and Bragg ptychography enabling computational image reconstruction. This shift, made practical by the coherence properties of third- and fourth-generation synchrotron sources is currently further progressing thanks to the improvement of reconstruction algorithms.

For each technique we discuss the resolution-determining factors, and the trade-offs between field of view, spatial and strain resolution. Special attention is given to operando capabilities, which have made diffraction imaging an indispensable tool for studying materials under realistic functional conditions in semiconductors, battery electrodes, and catalytic systems.

Recent experimental results from the ESRF illustrate these capabilities concretely, demonstrating how the new coherent flux delivered by fourth-generation sources is reshaping what is experimentally achievable — and pointing toward the opportunities that other facilities will be able to bring to this field in the coming decade.