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X-ray Ptychography: Recent Developments and Applications

High-resolution resolution X-ray tomography via burst ptychography

T. Aidukas, N. W. Phillips, A. Diaz, E. Müller-Gubler, M. Guizar-Sicairos, M. Holler

Paul Scherrer Institut, Forschungsstrasse 111, Villigen PSI, Aargau 5232, Switzerland

tomas.aidukas@psi.ch

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The resolution attained using X-rays has improved significantly, especially with the introduction of ptychography [1] – a coherent lensless imaging technique. While scanning the sample across the X-ray beam, a diffraction pattern is collected for each scanning position. Once the desired field-of-view is scanned, the recorded diffraction patterns are used to recover the amplitude and phase of the sample transmissivity by iterative phase-retrieval algorithms. Ptychography provides diversity to the measurement [2] via overlapped illumination. Combined with computational optimization routines the missing phase problem can be solved reliably if the forward model, i.e. the mathematical description of interaction of light and matter and its propagation to the detector, is accurate. In the presence of experimental imperfections, the physical measurement will deviate from the assumed forward model and degrade reconstruction quality. A common degradation manifests itself as blurring of the diffraction patterns, caused e.g. by poor spatial coherence of the illumination or by relative motion of the illumination and the sample.

We propose an image acquisition and reconstruction technique called burst ptychography, where for a given scan position and the same photon budget we capture many low-exposure frames, in the order of few milliseconds, for each scanning position. This allows us to resolve the temporal dynamics of the instabilities and decouple them into multiple images, thus we no longer require to infer them from a single image using mixed-state ptychography [3], which reduces algorithmic complexity. Despite the rather trivial image acquisition process, ptychographic reconstruction becomes challenging due to large data quantities and poor signal-to-noise ratio of each low-exposure image. The problem is especially difficult if the underlying instabilities change in nature or amplitude for each scan position. With burst ptychography we can mitigate the aforementioned issues, boost algorithm convergence, and reduce computational load.

To validate burst ptychography we imaged an integrated circuit sample and reconstructed it using burst ptychography, Fig.1(a), and mixed-state ptychography [3], Fig.1(b), which is a common alternative approach to mitigate experimental imperfections. The significantly better image quality of burst ptychography is attributed± to the refined sample scanning positions shown in Fig.1(c). The recovered experimental instabilities had an amplitude of 20 nm, making burst ptychography an ideal candidate to narrow the gap between X-ray and electron microscopy, especially for 4th generation X-ray sources. During the talk, I will introduce the computational and experimental approach of burst ptychography, which will be validated by experimental integrated circuit data reconstructed with a 4 nm voxel size in 3D.

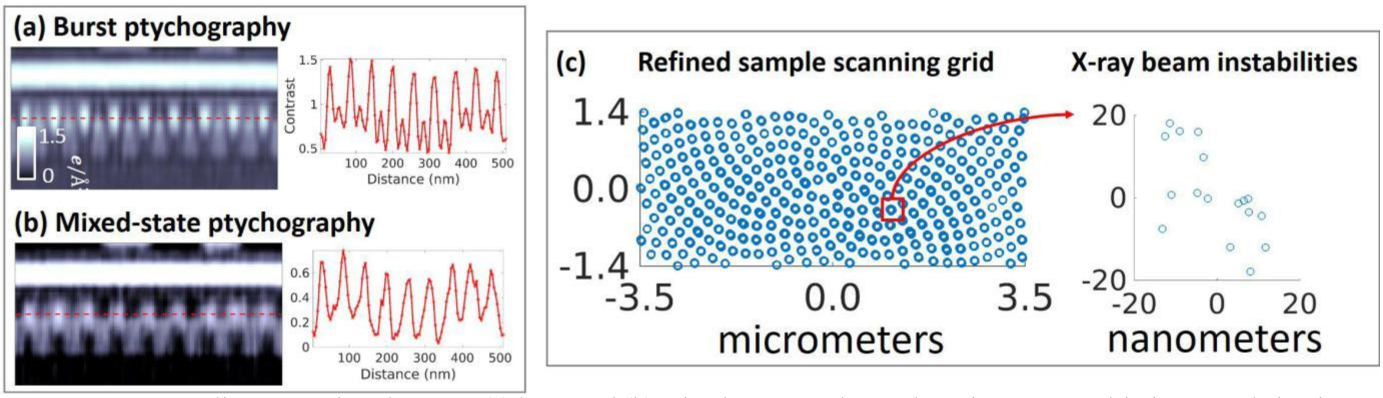

Figure 1. Image quality comparison between (a) burst and (b) mixed-state ptychography using a zoomed-in integrated circuit 3D reconstruction. (c) The improved image quality of burst ptychography is attributed to the X-ray beam instability correction.

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