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Grazing-Incidence X-ray Holography for Visualizing Surface Mesostructures

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Lensless X-ray coherent diffraction imaging (CDI), facilitated by ptychography, has emerged as a thriving field with promising applications in materials and biological sciences with a theoretical imaging resolution only limited by the X-ray wavelength. Most small-angle scattering based CDI methods use transmission geometry, which has limitations for studying nanostructures grown on opaque substrates or objects of interest comprising only surfaces or interfaces, including nanoelectronics, ultrathin-film quantum dots, photovoltaics, etc. To overcome the limitations, we developed coherent surface scattering imaging (CSSI) in grazing incidence reflection geometry that takes advantage of enhanced X-ray surface scattering and interference near total external reflection [1]. In grazing-incidence and reflection conditions, multiple scattering at the low incidence and/or scattering angles is an integral part of the coherent scattering from the surface features. We discovered that the dynamical or multibeam scattering promises 3D structural determination in a single view when the surface patterns cannot be effectively reconstructed by the conventional Fourier-transform approaches. To understand the problems, we developed a 3D finite-element-based multibeam-scattering analysis to decode the heterogeneous in-plane electric-field distribution required for faithfully reproducing the complex scattering features and 3D surface morphology, which is validated by experimental data quantitatively. This approach leads to the demonstration of hard-X-ray Lloyd's mirror interference or multi-beam surface holography that dominates the grazing-angle scattering. A first-principles calculation of the single-view holographic images resolves the surface patterns'3D morphology with nm resolutions, which is critical for ultrafine nanocircuit metrology [2]. These approaches pave the way for single-shot 3D structure determination at the new-generation synchrotron sources, such as the upgraded APS, crucial for visualizing irreversible morphology-transforming physical and chemical processes in a time-resolved, in situ, or operando fashion. In this presentation, we will also discuss the newly built featured beamline, the dedicated CSSI beamline at 9-ID, at the APS.

[1] T. Sun et al., Nature Photonics 6, 586–590 (2012).
[2] M. Chu et al., Nature Commun. 14, 5795 (2023). DOI: 10.1038/s41467-023-39984-3.

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I plan to submit also conference proceedings

No

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