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Directional dark-field imaging in full-field transmission X-ray microscopy

Dark-field X-ray imaging provides access to sub-resolution structural information by detecting small-angle X-ray scattering instead of attenuation or phase contrast [1]. However, existing implementations, such as grating-based [2] and speckle-based techniques [3], are typically limited to micrometer-scale resolution. Here, we present the first realization of directional dark-field imaging at the nanoscale within a full-field transmission X-ray microscope (TXM), enabling the retrieval of orientation-dependent scattering information from anisotropic nanostructures.

Our approach builds upon a previously established nanoscale dark-field TXM concept, which isolates scattered intensity in the back focal plane of a Fresnel zone plate (FZP) using a dark-field aperture [4]. We extend this setup by introducing an additional condenser aperture (C-AP) that selectively illuminates the sample from defined directions [5]. By sequentially blocking two-thirds of the condenser field in four orientations, the system becomes sensitive to direction-specific scattering components. Combining these directional projections yields maps of both scattering magnitude and orientation directly in projection space.

The method was validated using a Siemens star test pattern and applied to human tooth enamel, revealing nanoscale orientation distributions of hydroxyapatite crystallites. The implementation requires only minimal hardware modifications to existing TXM systems, preserving high spatial resolution (~115 nm, 20% MTF). These results mark an important step toward dark-field tensor tomography and size-selective nanoscale imaging, opening new possibilities for structural characterization in materials science, biology, and biomedical imaging.

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