Differentially Encoded Holography for X-Ray Coherent Imaging

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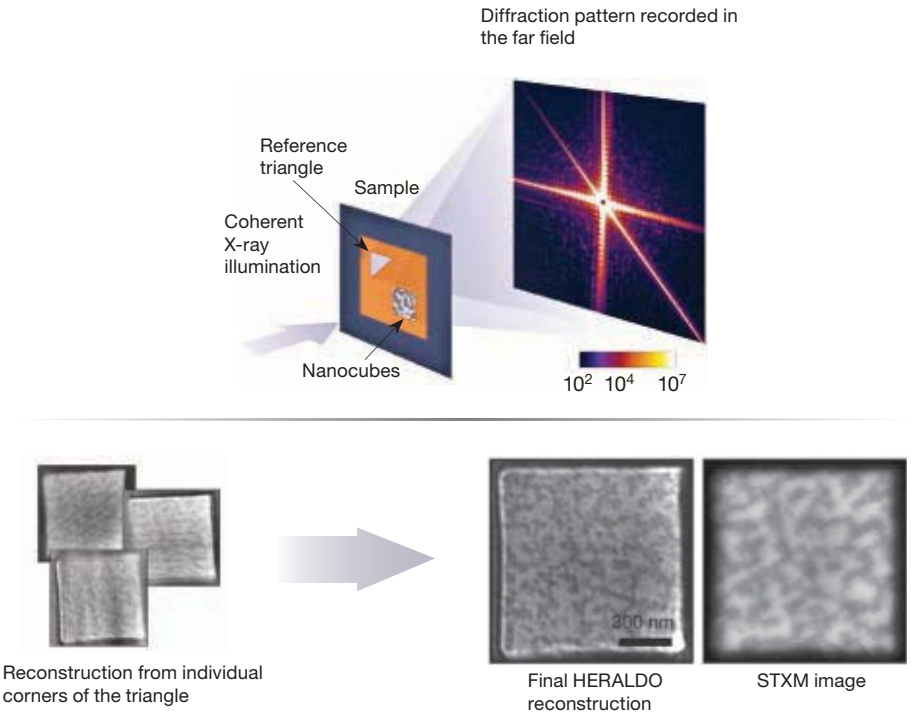
Fourier transform holography (FTH) has played an important role in coherent X-ray imaging,[1] enabling, for example, quantitative imaging of magnetic domains at high resolution. With the advent of bright, short pulses from X-ray free-electron lasers (X-FELs), coherent diffractive imaging enables femtosecond snapshots of dynamic phenomena with unprecedented temporal and spatial resolution. However, the resolution of FTH is limited by the size of the point reference that can be fabricated. Although in principle the resolution can be improved through deconvolution, in practice an accurate knowledge of the complex-valued distribution of the point source is difficult to obtain.

A generalization of FTH can be made by using a suitable extended reference (rather than a pinhole), and then using differential operators in the reconstruction procedure, a technique we term holography with extended reference by autocorrelation linear differential operation (HERALDO).[2] For HERALDO, the phase of the field diffracted by the object is encoded through interference with a boundary wave arising from a sharp feature on the extended reference. This added flexibility permits us to use structures that are naturally sharp, such as crystal corners or thin nanotubes, to improve resolution.

Using a lithographically fabricated mask, we have recently shown that HERALDO can achieve superior resolution over FTH with comparable signal-to-noise ratio in the reconstruction.[3] We also show that the imaging performance of HERALDO compares favorably with iterative phase retrieval[4] and with state-of-the-art X-ray zone-plate microscopes, for a low-contrast sample consisting of iron/iron-oxide nanocubes of 18 nm in size.[3]

We further demonstrated the capability of improving image resolution beyond the reference fabrication limitation by combining reconstructions arising from different sharp features of the same reference. More recently, good quality reconstructions were obtained from a table-top high-harmonic source with a single pulse of 20 fs,[5] which demonstrates the effectiveness of HERALDO in single-shot scenarios, a crucial capability for imaging using the new X-FELs. Because of the flexibility in choosing the reference structure and its simple, closed-form reconstruction, HERALDO offers an attractive platform for X-ray coherent diffractive imaging.



Experimental setup for X-ray holography using HERALDO. An extended reference with sharp features (triangle corners) is placed in the vicinity of the object of interest (viewing window with iron/iron-oxide nanocubes). Three reconstructions are computed in closed-form and combined to yield the final image. A scanning transmission X-ray microscope (STXM) image is shown for comparison.

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