Spectrally resolved lensless imaging with ultra-broadband high-harmonic sources

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Abstract: *We present a novel method for high-resolution coherent diffractive imaging using ultra-broadband sources. By generating coherent pulse pairs with a tunable time delay, Fourier-transform spectroscopy techniques can be combined with coherent imaging. In this way, all spectral bandwidth limitations in diffractive imaging can be removed, and spectrally resolved lensless imaging becomes possible with sources that extend into the soft-X-ray spectral range.*

Microscopy with extreme-ultraviolet (EUV) and soft-X-ray radiation has the potential to provide a unique window into the nanoworld. While the short wavelength radiation enables a resolution on the nanometer scale, inner-shell absorption edges of various elements provide intrinsic contrast and the ability to perform element-selective imaging. As the fabrication of efficient and aberration-free optical components becomes increasingly challenging for such short wavelengths, lensless imaging methods are a powerful alternative for the development of practical high-resolution EUV microscopes.

In lensless imaging a coherent diffraction of an object is recorded directly, and an image of the object is then reconstructed by numerical algorithms rather than physical optical components. The main challenge is to retrieve the phase associated with the diffraction pattern, as a camera only records intensity. One major requirement that has remained in diffraction-based imaging methods is the need for a well characterized spectrally narrowband source. To overcome this limitation and enable efficient imaging with table-top high-harmonic generation (HHG) sources, which are intrinsically ultra-broadband, we have developed a new imaging method based on the diffraction of coherent pulse pairs. By recording a series of diffraction patterns as a function of the time delay between two coherent pulses, a Fourier-transform spectrum can be recorded at each pixel in the diffraction pattern. From this dataset, quasi-monochromatic diffraction patterns can be reconstructed throughout the full source spectrum, and the full source flux is used to continuously illuminate the object. Combining this two-pulse approach with phase retrieval techniques enables spectrally resolved EUV imaging, or robust image reconstruction through the use of multiple Fresnel diffraction patterns in a multi-wavelength phase retrieval scheme.

To enable accurate time-delay scanning, we have developed an ultra-stable interferometer based on birefringent wedge pairs, which allows the generation of tunable and intense HHG pulse pairs with 2.7 attosecond timing stability (0.8 nm path length). HHG is produced by pairs of 1.5 mJ, 20 fs pulses at 300 Hz repetition rate, produced by an optical parametric chirped pulse amplification system. With this setup, Fourier transform scans have been produced with harmonics up to the Al absorption edge at 73 eV (17 nm wavelength). In this presentation, I will present the principles and capabilities of our approach, and show recent results on EUV imaging and spectroscopy.