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Material-resolved and thickness-sensitive lensless imaging using high-harmonic generation: from diffractive shear interferometry to ptychography

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Abstract. Microscopy with table-top high-harmonic generation (HHG) sources enable high-resolution imaging with excellent material contrast, due to the short wavelength and numerous element-specific absorption edges available in this spectral range. However, accurate characterization of dispersive samples in terms of composition and thickness remains challenging due to the limitations of lens-based optics in this spectral range. Here, we performed spectrally resolved lensless imaging using multiple high harmonics. The diffractive shearing interferometry reconstruction serves as a foundational step for element-sensitive metrology, while ptychographic reconstruction enabled the retrieval of high-precision spectral imaging and quantitative thickness mapping. Our non-destructive method offers a powerful tool to extract both the material composition and layer thicknesses of complex nanostructured samples.

Imaging with HHG sources presents an attractive option for high-resolution inspection applications, as many materials exhibit unique absorption and transmission properties within the EUV wavelength range. Unlike traditional microscopy, which requires lenses for photons or electrons, coherent diffractive imaging (CDI) aims to reconstruct images from recorded diffraction patterns through numerical phase retrieval [1]. Reflection-mode ptychography enables nondestructive, chemically specific thickness measurements for substrate-based samples [2]. In contrast, transmission-mode imaging offers a practical approach for characterizing partially transparent, yet compositionally complex samples.

In this work, we performed a series of spectrally resolved lensless imaging experiments on a sample with a 3D compositional structure. Diffractive shearing interferometry (DSI) [3] provides accurate spectrally resolved reconstructions (Fig.1a,b)) and serves as a foundational step toward element-sensitive metrology. Meanwhile, incorporating prior knowledge of the illumination spectrum, ptychography allows us to simultaneously reconstruct the complex electric field of the probe beam and the complex field of the sample, as shown in Fig.1c,d). This experiment demonstrates both the capabilities and the limitations of DSI (and in general single-shot CDI-based methods) for element-resolved imaging. Through ptychography,

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we further retrieve high-precision monochromatic reconstructions and extract quantitative layer thicknesses, as shown in Fig.1f). We use HHG beams carrying orbital angular momentum as a means of structured illumination, further improving imaging performance [4]. Our non-destructive method demonstrates the capability to accurately extract information on the material composition and layer thicknesses of complex nanostructured samples.

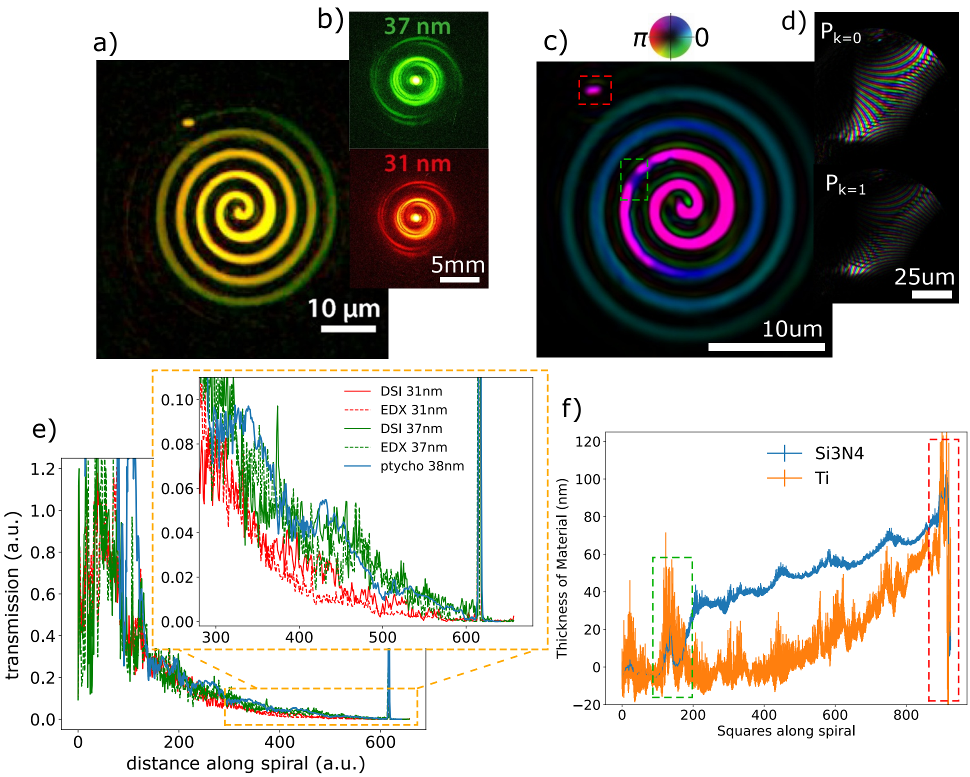

Figure 1. Reconstructed results from a,b) DSI and c.d) ptychography measurements. e) Comparison of the relative transmission along the spiral sample, from center outward. f) Thickness of two-layer material from ptychographic reconstruction.

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