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Reflection Ptychography via Auto Differentiation on a High Harmonic EUV beamline

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Abstract: We demonstrate our beamline using a table-top HHG EUV source for lensless imaging application in reflection mode. The sample reflection function is reconstructed using an auto-differentiation based ptychographic algorithm built on TensorFlow platform.

1. EUV metrology beamline

The beamline is configured for grazing-incidence lensless microscopy with EUV light, generated by a high-flux High Harmonic Generation (HHG) source. This table-top HHG system (Active Fiber Systems) is driven by a 300 femtosecond, 100 W infrared fiber laser (λ = 1030 nm) at a repetition rate of 600 kHz, which is compressed to 28 femtoseconds. The light is focused into a pressurized Argon gas jet of 10 bar, resulting in a flux of $> 10^{11}$ photons/second at a wavelength of 18 nm as demonstrated in [1].

A majority of the IR light is rejected by two flat mirrors, set at the Brewster angle for infrared light at 1030 nm, while still reflecting EUV light. Residual light is filtered by two Aluminium foils with a thickness of 200 nm.

A set of multi-layer mirrors (MLM) selects a single harmonic at 18 nm with a FWHM of 0.6 nm and reflectivity of 21%. This monochromatic beam is focused by an ellipsoidal mirror. The ideal focal spot size should have a size of a few microns. However, rough alignment of this ellipsoidal mirror resulted in a probe size of 32 by 86 micron. The enlarged probe size requires a longer than ideal propagation distance so that the over-sampling condition can be fulfilled. This limits the ultimate resolution of the sample that we can reconstruct as the size of the smallest resolvable feature is inversely proportional to the propagation distance for Fraunhofer (far-field) diffraction.

The sample is placed in a five degrees-of-freedom (DOF) stage-assembly, for scans in the sample plane (x,y,z), angle of incidence and azimuth direction. The diffracted light is acquired by a square 4 megapixel full-vacuum camera (PI-MTE3) with a pixel size of 15 μm, placed 88 mm downstream from the sample.

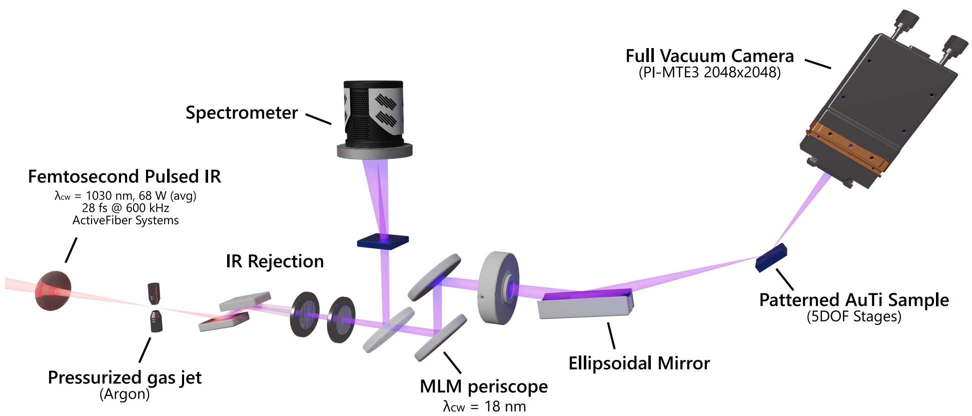

Fig. 1. The IR light has to be separated from generated EUV light due to the low conversion ratio. A single harmonic at 18 nanometer is selection through a set of multilayer mirrors (MLM). The beamline is equipped with an transmission spectrometer to assess the EUV source.

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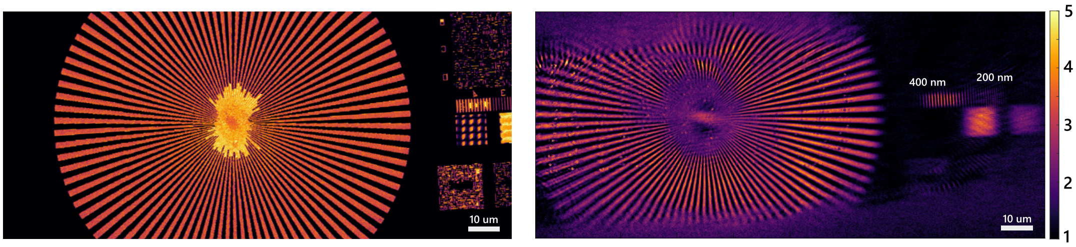

Fig. 2. a) A 20 nanometer gold titanium (AuTi) is deposited on a silicon substrate and patterned with various structures, including an erroneous Siemens star as depicted in the SEM image. b) The Siemens star is partially scanned and is resolved using PtychoFlow. The highest resolution resolved within the Siemens star is 230 nanometer. A part of a chirped grating is resolved down to 200 nanometer lines.

2. Ptychography in reflection mode using automatic differentiation based algorithm on Tensorflow platform

We demonstrate our first reflection-mode ptychography result of the sample's reflection function, reconstructed from a set of 255 far-field diffraction patterns in Fig.2. The sample is patterned in a single-layer 20 nanometer thick gold-titanium (AuTi) on silicon substrate. In the experiment, we scan a probe (a focused EUV beam) over the sample surface in 2D grid-like pattern and acquire a diffraction pattern at each scanning position with an exposure time of 200 ms per position. The overlap between neighboring scanning positions is about 85 percent.

In the reflection mode, the probe beam incidents on the sample at 20 degrees grazing angle with respect to the sample surface, while the camera is placed perpendicular to propagation direction of the reflected beam. As a result, tilted plane correction (TPC) is applied to each diffraction pattern to compensate for this effect prior to the actual ptychography reconstruction.

The ptychography algorithm is developed by researchers at both TU Delft and Utrecht University based on the automatic differentiation (AD) method [2]. The reconstruction is achieved via iterative optimization with the sample, the probe, the scanning positions, and the propagation distance (or the wavelength) as variables. The core of the algorithm is the calculation of the gradient with respect to each variable, which is now done by the AD method, instead of deriving an analytical formula or using any numerical method (e.g., finite difference). The AD method provides great flexibility to the algorithm and its development.

Our Ptychography algorithm is implemented on the TensorFlow platform [3] and is named PtychoFlow. TensorFlow provides well established AD functionality as well as a number of other benefits such as the advanced optimizers and the integrated GPU acceleration.

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