Phase Retrieval in Lensless Coherent Diffractive Imaging

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Introduction

Extreme ultraviolet (EUV) plasma sources are currently being investigated as next-generation light sources for photolithography, a technique that is utilized in semiconductor manufacturing, with the potential to resolve nanoscale features. Although EUV radiation is known to be created by irradiating a tin droplet source with a pulsed laser, the correlation between droplet structure and radiation intensity has not been explored.

Coherent diffractive imaging (CDI) is a powerful "lensless" microscopy technique that can be used to produce high-resolution images of non-crystalline structures by utilizing an iterative phase retrieval algorithm to reconstruct the image of an object from its diffraction pattern. By examining the structure of droplets with CDI, we can probe the relationship between plasma luminosity and droplet topography and optimize droplet sources for mass semiconductor manufacturing.

Experimental Setup

We utilized a 632 nm HeNe laser to illuminate our sample with a collimated beam and collected the diffraction pattern with a CCD camera, blocking the bright center with a beam stop to prevent light saturation.

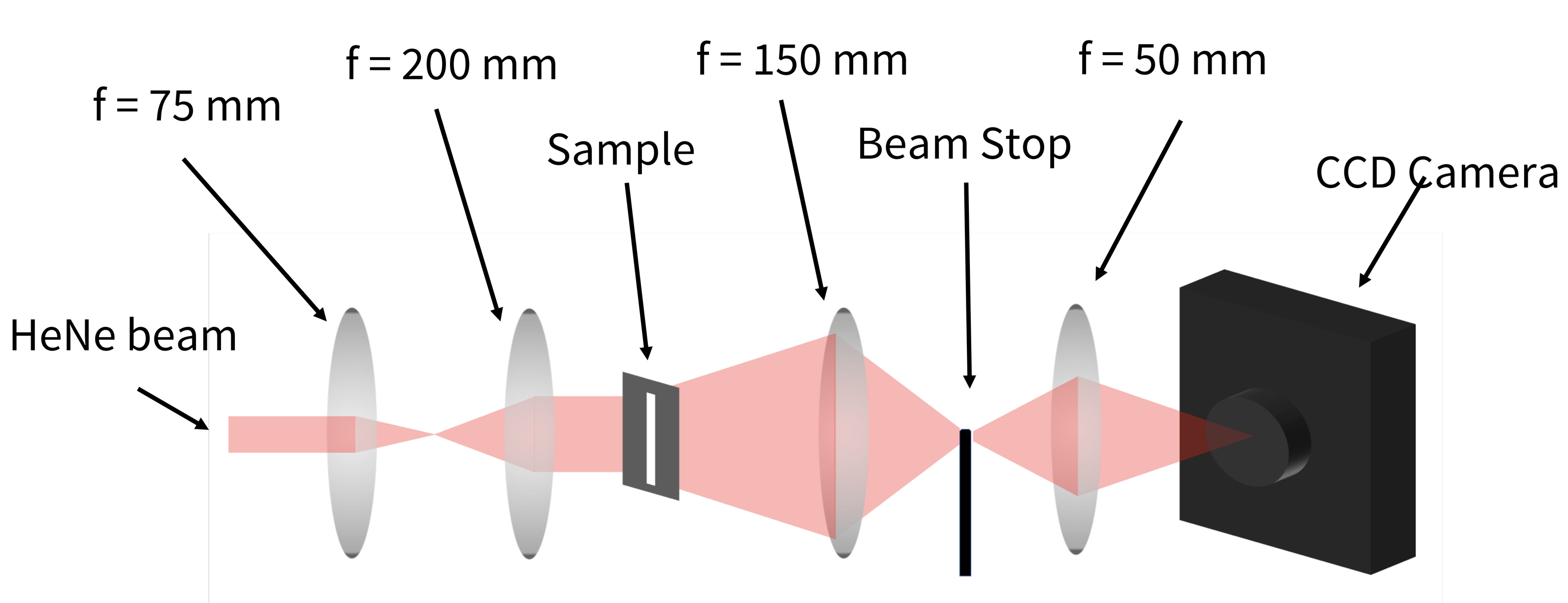

Figure 1: An annotated schematic of the experimental setup.

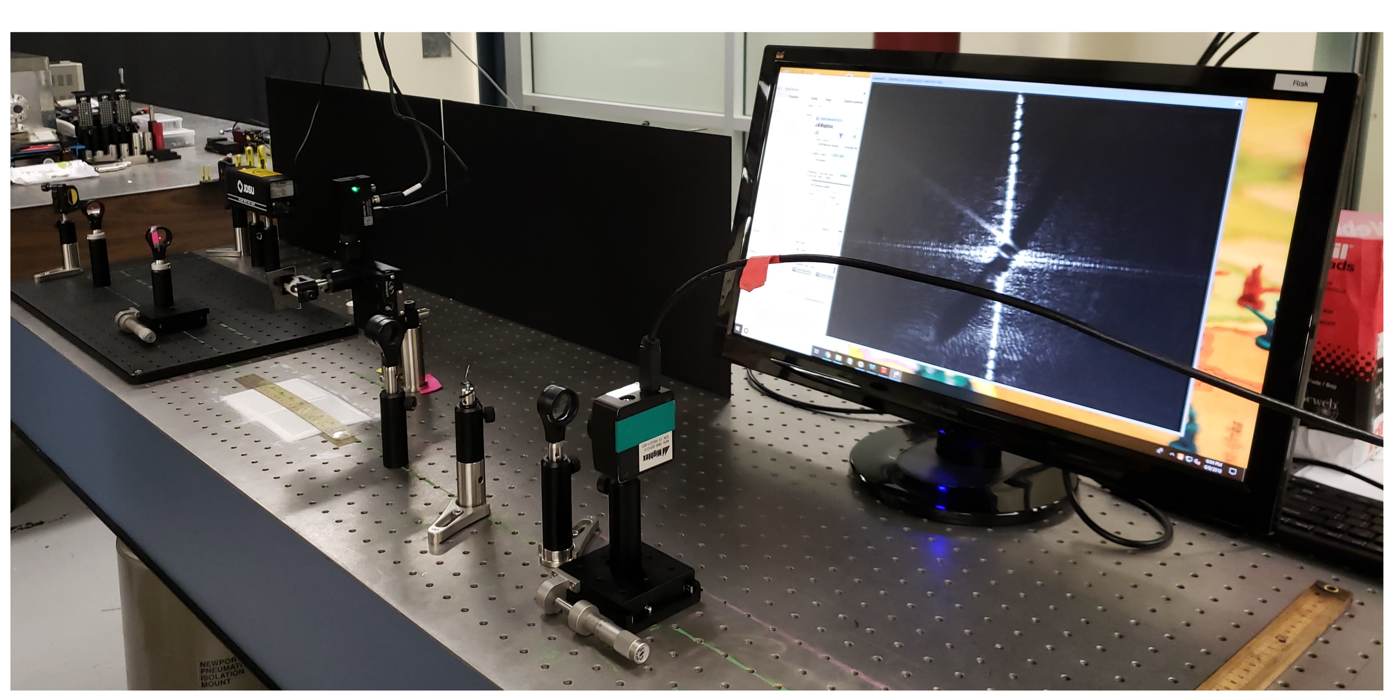

Figure 2: The experimental setup. We utilized two horizontal stages to adjust the positions of the camera and the second lens and mounted the resolution sample on a vertical motorized stage.

Phase Retrieval Algorithm

The CCD camera used to collect the diffraction images only measures light intensity; however, this measurement is incomplete because light waves have a phase component in addition to their amplitude. Therefore, the reconstruction of an image from its diffraction requires the recovery of the object's phase information through a hybrid input-output algorithm.

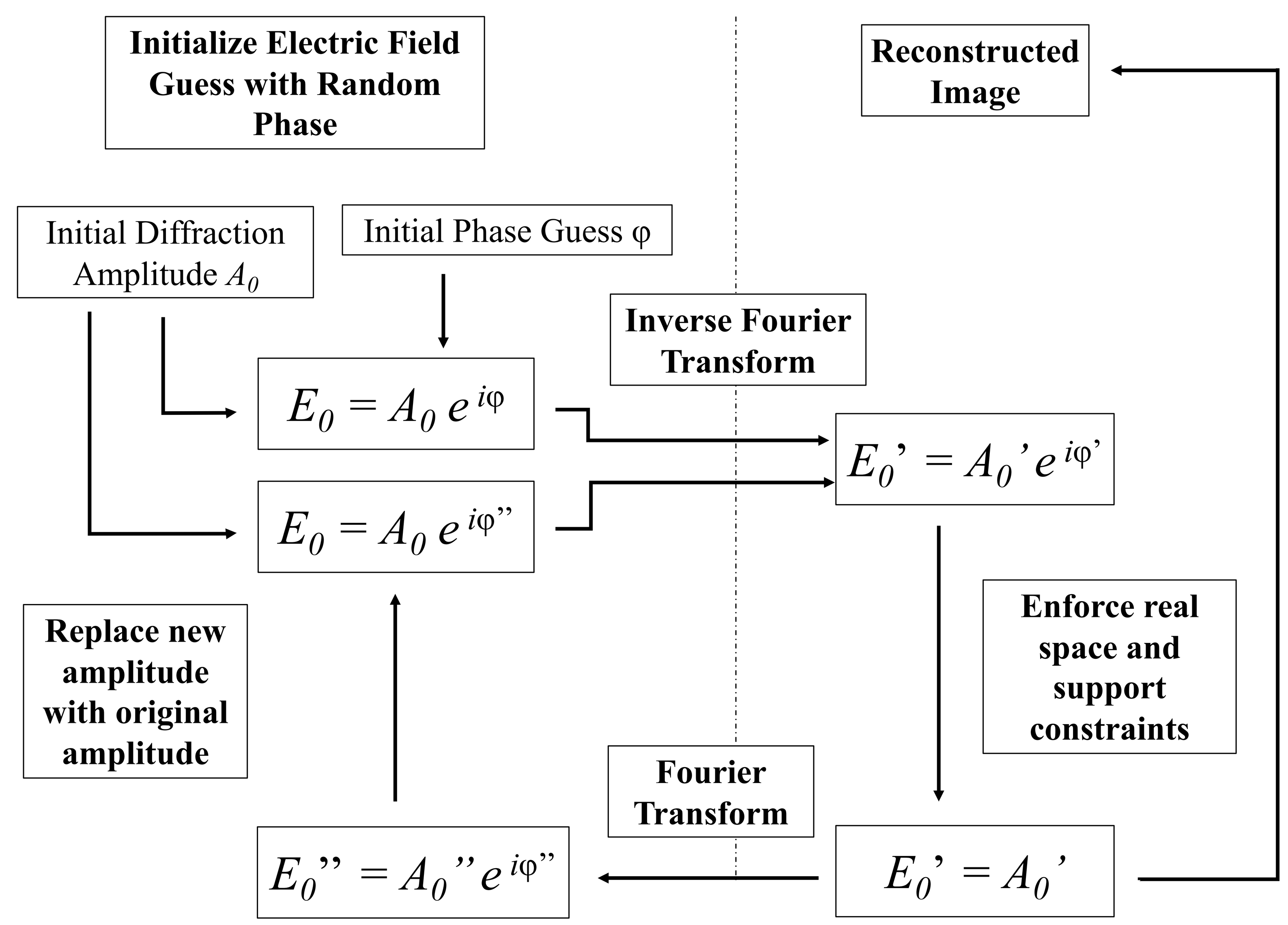

Figure 3: A visual representation of the hybrid input-output algorithm. By enforcing physical constraints on the image, the algorithm is forced to converge.

Initial Tests

We simulated diffraction patterns by oversampling object images and removing the phase of their Fourier Transform. The algorithm begins to converge within 100 iterations, assuming a noiseless image and a complete diffraction pattern.

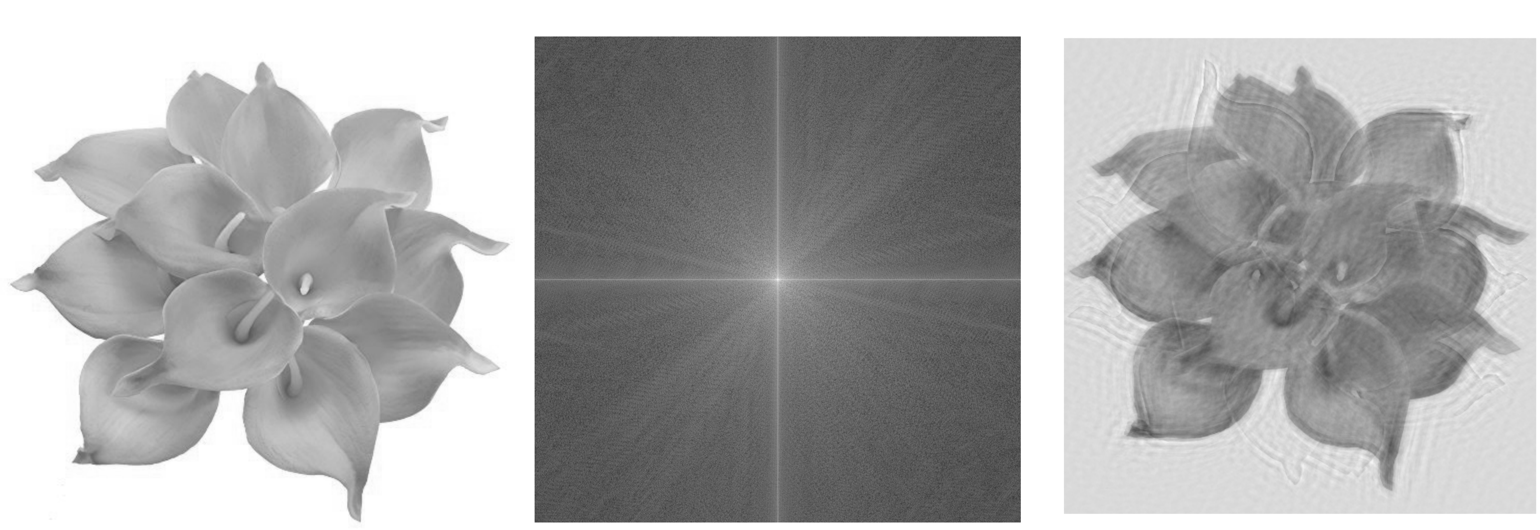

Figure 4: From the far left: A grey scale image of flowers; the Fourier Transform of the image, and the reconstructed image generated by passing the second image through 1000 iterations of the algorithm

Results and Error Analysis

Although the algorithm was able to reconstruct simulated diffraction images, the experimental diffraction images captured by the CCD camera were saturated and fairly noisy. We stacked 200 diffraction images taken with a 5 ms exposure time to increase the signal-to-noise ratio and subtracted background noise, but we was only able to marginally improve the reconstruction.

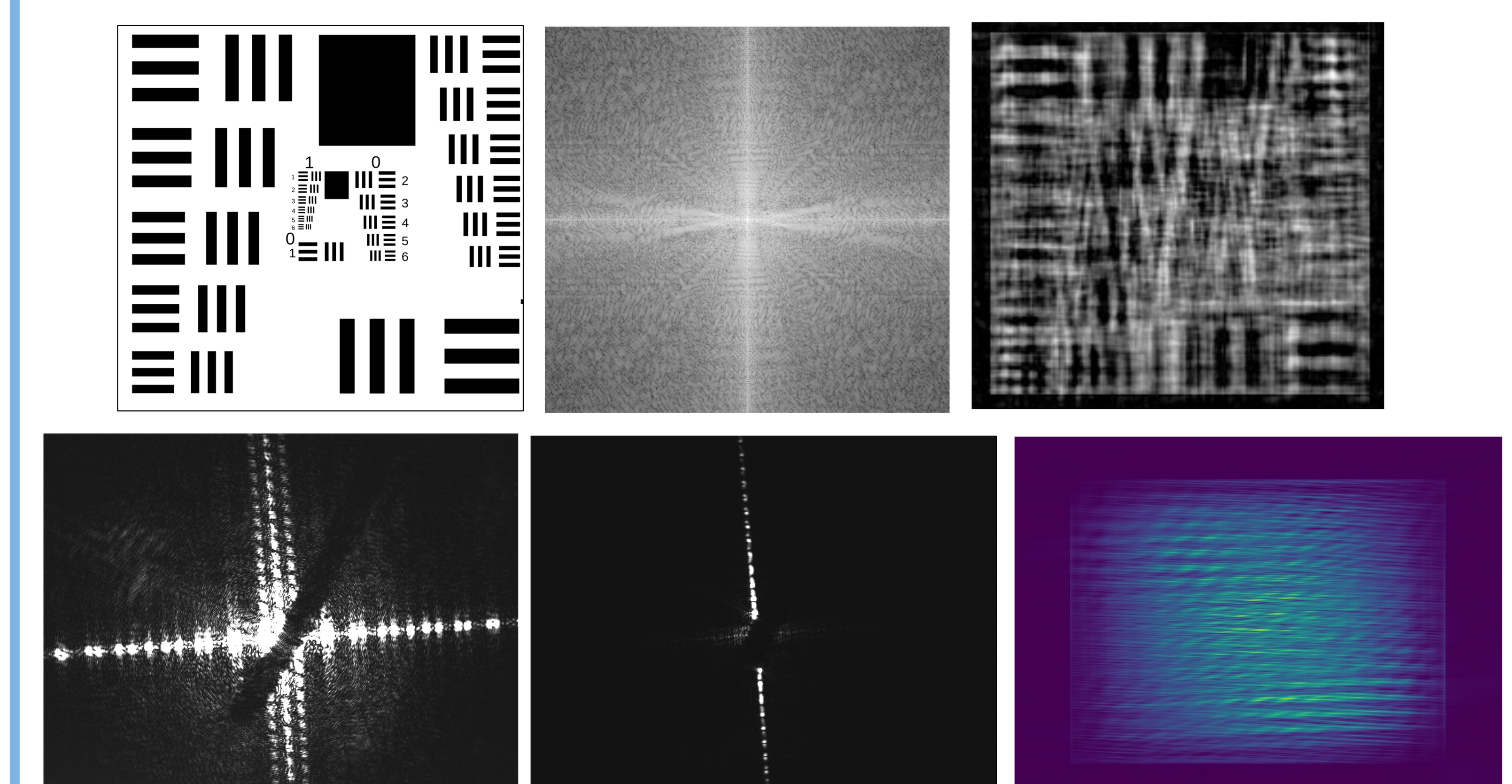

Figure 5: Clockwise from the upper right: The resolution sample, its simulated diffraction pattern, the corresponding reconstruction, the experimental diffraction pattern, the pattern with a lower exposure time, and the noisy reconstruction of a horizontal section.

Future Work

In order to reconstruct experimental diffraction images, we need to identify and mitigate noise and bit saturation. We can utilize ptychographic imaging to improve the algorithm by physically oversampling the diffraction pattern with the use of a motorized stage. In the future, we hope to build a droplet source and begin to probe the topography of droplets through gravity-assisted ptychographic coherent diffractive imaging, where the movement of liquid droplets under gravity mimics the movement of the stage, allowing us to image the three-dimensional structure of droplet EUV sources.

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References

1. Giewekemeyer, K., et. al. *Ptychographic coherent x-ray diffractive imaging in the water window*. Opt. Express
2. Odstrcil, M., et.al. *Nonlinear ptychographic coherent diffractive imaging*. Opt. Express24.
3. Osherovich, E. *Numerical methods for phase retrieval.* PhD thesis.