Actinic EUV Mask Inspection via Coherent Diffractive Imaging Using a Tabletop High Harmonic Source

STROBE — BUILDING THE MICROSCOPES OF TOMORROW

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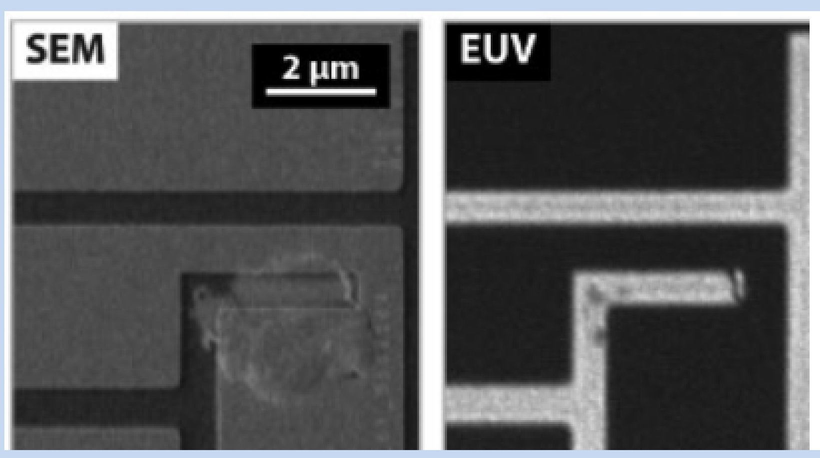
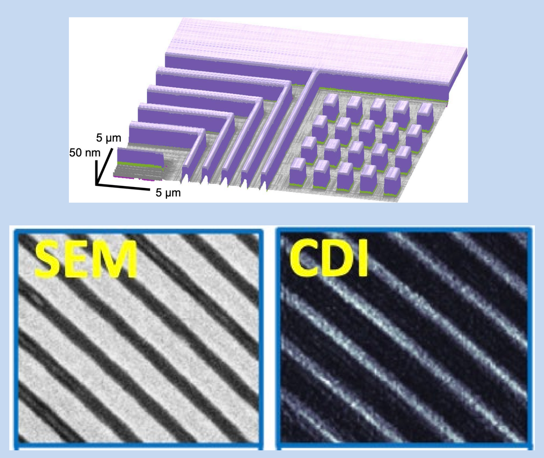
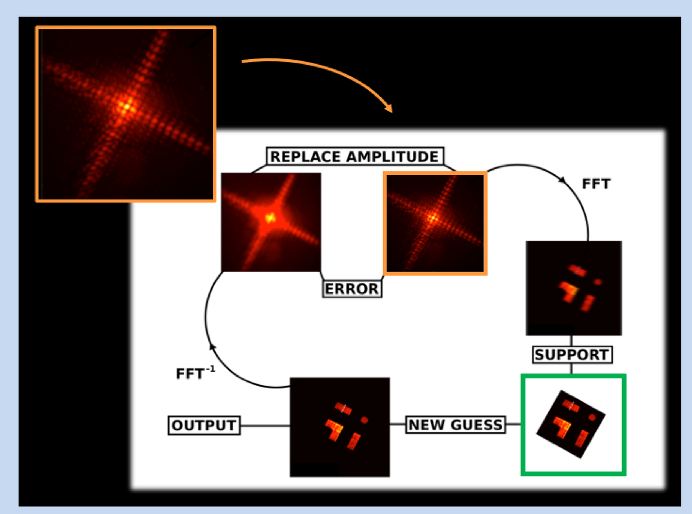
Introduction

As extreme ultraviolet (EUV) lithography is moving to high volume manufacturing, the fabrication and inspection of defect-free EUV masks remains one of the most critical and challenging issues in EUV metrology. Non-actinic inspection techniques struggle with low spatial resolution and/or exaggeration or distortion of the actual impact of photomask defects on patterned wafers. Consequently, an EUV actinic inspection tool is extremely attractive for inspection of the printability of EUV mask defects, as well as for in-fab monitoring for possible defects emerging from extended usage. We are developing such a Tabletop EUV Actinic Microscope System (TEAMS) by combining tabletop high harmonic EUV sources and coherent diffractive imaging techniques.



EUV image from SHARP, LBNL illustrating need for actinic imaging





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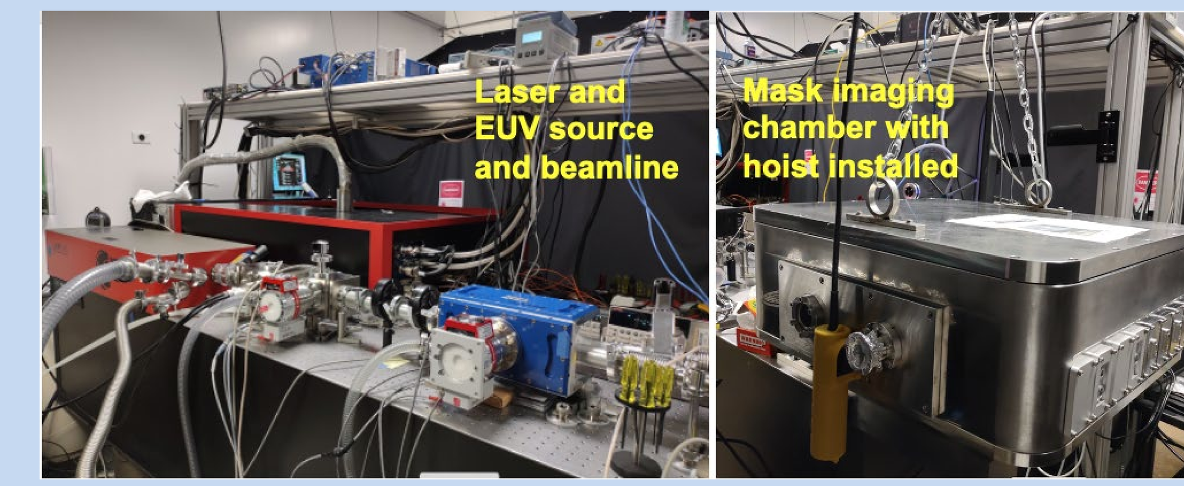
Configuration of the Tabletop EUV Actinic Microscope System

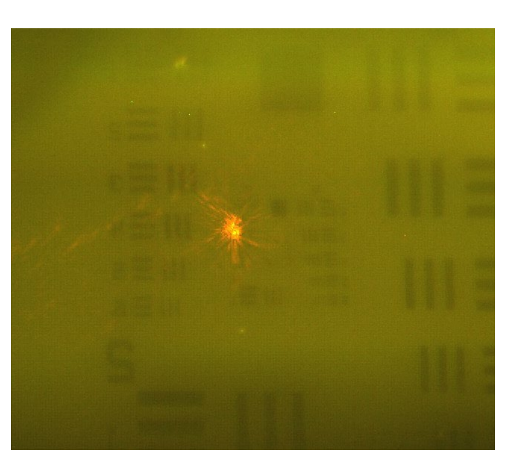
- The driving laser generates ultrafast laser pulses at ~790nm wavelength, with 30fs pulse duration and 2.5mJ pulse energy at 5kHz repetition rate.
- High harmonic (HHG) upconversion in a waveguide filled with ~1 atm He generates bright coherent 13.5nm EUV beams.

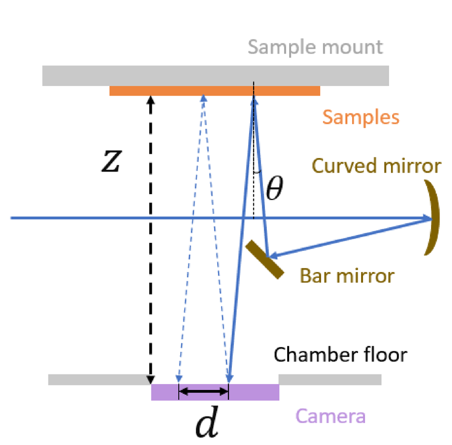


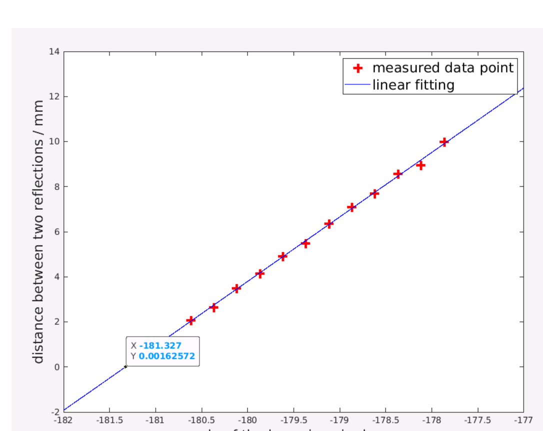
- A Mo/Si multilayer curved mirror (CM) and flat mirror (FM) focus and direct the beam onto the mask at a 6° angle of incidence, The reflected and diffracted EUV light is captured by an EUV CCD sensor, which was mounted 40mm below the EUV photomask
- The movement of the EUV photomask is accomplished by two sets of stages
  - The EUV photomask is mounted on a 2-axis 200-mm motion stage with ~1µm precision for coarse positioning
  - The CM is mounted on a set of 3-axis piezomotor stage, with ~10s nm repeatability, for the CDI scan
  - Subsequent position correction can refine the position to <nm accuracy

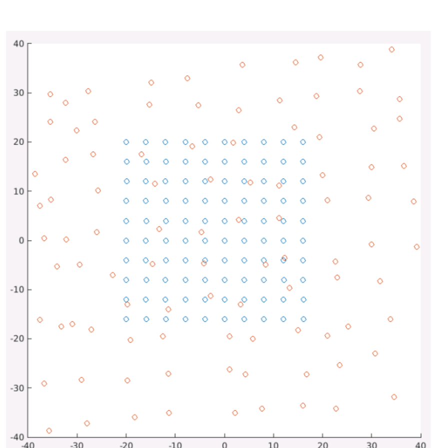
System Calibration Using Visible Lasers

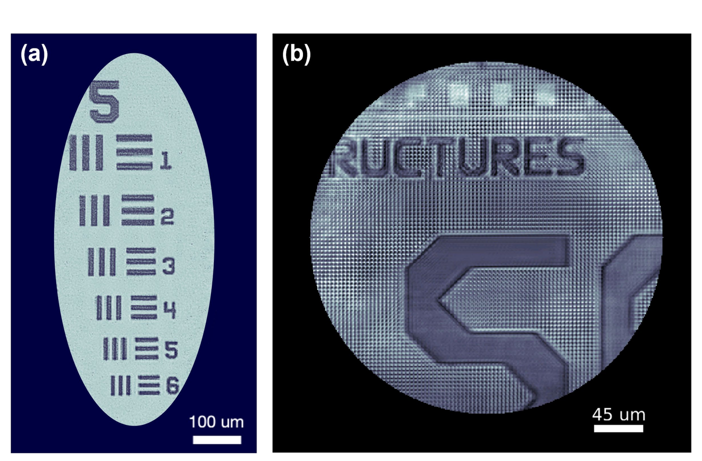
- Designed and implemented an optical microscope to assist sample navigation in the vacuum.







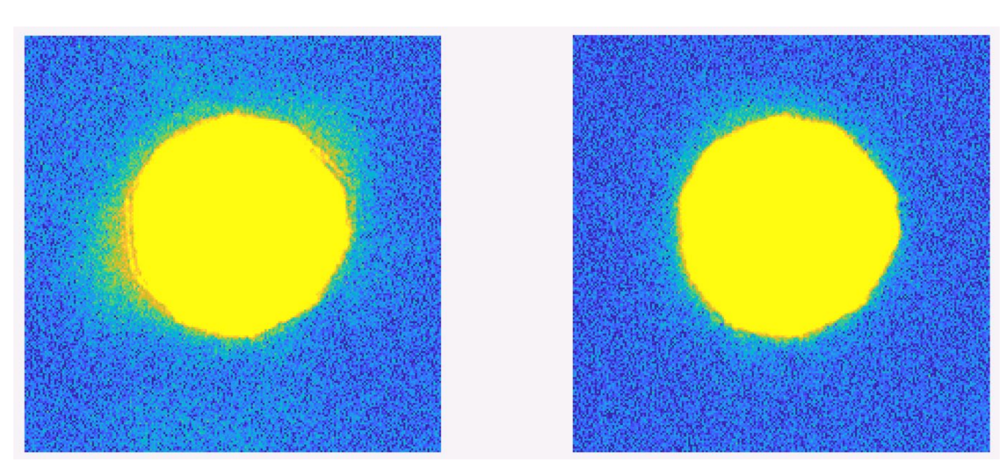




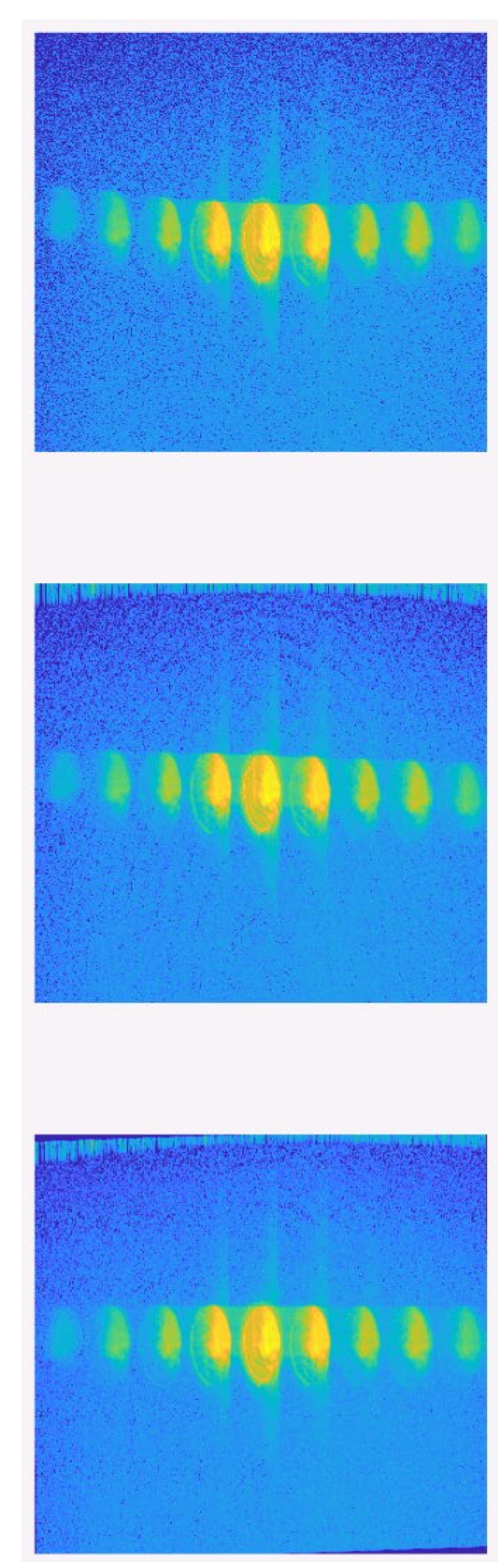
- Used the double reflection between the sample and camera to calibrate the sample-to-camera distance and beam AOI.
- Corrected for the beam center movement on camera.
- Demonstrated diffraction-limited ptychographic coherent diffractive (CDI) imaging using visible lasers.

Preliminary EUV CDI Demonstration

- Ptychographic data pre-processing pipeline
  - Background subtraction
  - Tilted plane correction
  - Diffraction pattern rotation
  - Ptychographic scan position correction
- Scatterometry measurement for defect detection



- Preliminary ptychographic reconstructed images of the corner of a 1D grating on an EUV photomask from Imec - artifacts at the edges of the grating lines need further investigation.



Preliminary diffraction patterns on the corner of a 1D grating on an EUV photomask from Imec

Summary and Future Directions

- Summary:
  1. We have built a tabletop EUV photomask inspection system based on ptychographic imaging and a tabletop 13.5nm HHG source.
  2. The TEAMS system has been calibrated and tested using visible lasers.
  3. The EUV source has been integrated into the TEAMS system, and actinic inspection on a EUV photomask has been performed.
  4. We are in process of improving EUV ptychographic reconstruction quality, which is standard for a new setup.
- Future directions:
  1. Upgrade light source to commercial system (current version is pre-prototype).
  2. Implement better diagnostic setups.
  3. Implement more powerful phase retrieval algorithms.
- More exciting work: see Poster #037 by Esashi