# 13.2 nm Table-Top Inspection Microscope for Extreme Ultraviolet Lithography Mask Defect Characterization

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**Abstract:** We report on a reflection microscope that operates at 13.2-nm wavelength with a spatial resolution of 55±3 nm. The microscope uses a table-top EUV laser to acquire images of photolithography masks in 20 seconds.

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Extreme ultraviolet lithography (EUVL) is the leading contender for printing the new generations of semiconductor chips at the 22 nm half-pitch node and beyond [1]. This technology has been demonstrated at laboratory and beta-tool scales but several issues, including the fabrication of defect-free masks, need to be addressed before it can be implemented for mass production of chips. This includes the need to develop metrology tools capable of detecting printable defects on EUVL masks. The most reliable way of detecting printable defects is to image the Mo/Si coated mask at the wavelength employed in the printing process, 13.5 nm. This enables characterization of absorption contrast defects as well as phase defects generated from imperfections within the layers of the resonant-reflective multilayer coating.

Demonstrations of high resolution actinic aerial microscopes have until now been conducted at synchrotron facilities where 13.5 nm wavelength radiation from bending magnets provides the required illumination [2, 3]. Transitioning EUV inspection microscopes into compact devices to inspect EUVL masks on-site is possible but requires table-top light sources with high brightness and flux near 13.5 nm. These requirements are met by recently developed EUV lasers [4, 5].

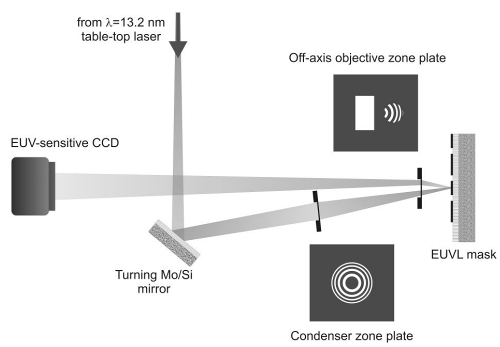


Fig. 1. Schematic setup of the microscope (not to scale).

We have implemented an actinic microscope suitable for mask inspection using a table-top, plasma-based, collisional 13.2 nm wavelength EUV laser [4, 5] in combination with specialized Fresnel Zone Plates (FZP) [6]. The EUV laser operates at 5 Hz, producing highly monochromatic pulses ($\Delta\lambda/\lambda < 1\text{x}10^{-4}$) with moderate spatial coherence (1/20 of the beam diameter) [7] and an average power of ~1 μW. The setup of the microscope is shown in Figure 1. The output of the laser is guided to a condenser FZP by a Mo/Si multilayer coated mirror. The 38 mm focal length, 0.06 NA condenser illuminates the sample at an incidence angle of 6 degrees. This geometry was selected to mimic the illumination conditions of a 4×-demagnification EUVL stepper with a numerical aperture of 0.25 [8]. A 1 mm focal length off-axis FZP collects the reflected light and forms a magnified image onto an EUV sensitive charge coupled detector array (CCD). The objective zone plate is an off-axis sub-aperture of a full parent zone plate lens of 330-μm diameter, an outer zone width of 40 nm, and a focal length of 1 mm. The pupil diameter is 120 μm, defining a NA of 0.0625, and its center is displaced 100 μm from the axis of the parent zone plate. An uncoated rectangular aperture next to the off-axis objective zone plate transmits the incoming condensed laser beam illumination. To increase throughput the support membrane thickness was reduced to 40 nm. The off-axis zone plate enables near-normal incidence imaging of the mask surface, minimizes aberrations, and provides incoherent illumination conditions by matching the NA of the condenser.

The object used to test the microscope's spatial resolution consisted of Ni absorber grating structures with half-pitches ranging from 80 to 500 nm patterned on the surface of a Mo/Si coated mirror. Figure 2 shows EUV images of elbow patterns with 140 nm, 120 nm, 100 nm, and 80 nm half-pitch. The images were obtained at a magnification of 610× at which each pixel on the CCD corresponds to 22 nm in the sample plane. The exposure time was 20 seconds, corresponding to 100 laser shots. Measurements of the intensity modulation from several lineouts taken from these images indicate that, according to the Rayleigh resolution criterion, all structures are well resolved.

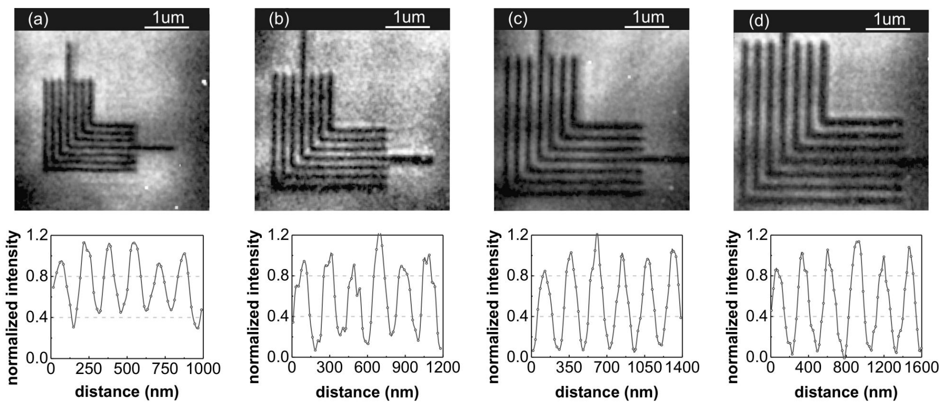


Fig. 2. EUV images and corresponding intensity cross-sections of elbow patterns with (a) 80 nm half-period, (b) 100 nm half-period, (c) 120 nm half-period, and (c) 140 nm half-period. The images were obtained with exposures of 20 second at a magnification of 610×.

The spatial resolution limit of the microscope, in the absence of smaller half period gratings on the sample, was determined by analyzing the images of figure 2 with a global resolution assessment algorithm [9] and independently using a knife edge test. From this analysis, a spatial resolution of (55±10) nm was obtained. The knife-edge test yielded a resolution corresponding to a half-pitch grating spatial resolution of (55±3 nm). This resolution exceeds the specifications set for the 22 nm technology half-pitch node. Forecasted improvements in the throughput of the microscope are expected to reduce the exposure time to a few seconds.

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[1] International Technology Roadmap for Semiconductors.

[2] Goldberg, K.A., et al. *Photomask Technology 2007*. 2007: Proc. of SPIE.

[3] Osugi, M., et al., Japanese Journal of Applied Physics, 2008. **47**(6): p. 4872-4977.

[4] Rocca, J.J., et al., Optics Letters, 2005. **30**(19): p. 2581-2583.

[5] Wang, Y., et al., Physical Review A, 2005. **72**.

[6] Anderson, E.H., IEEE Journal of Quantum Electronics, 2006. **42**(1): p. 27-35.

[7] Liu, Y., et al., Optics Express, 2006. **14**(26): p. 12872-12879.

[8] Barty, A., et al. *22nd Annual BACUS Symposium on Photomask Techology*. 2002: proceedings of SPIE.

[9] Wachulak, P.W., et al., Journal of the Optical Society of America B, 2008. **25**: p. B20-B26.