Actinic EUV Mask Inspection Beyond 0.25 NA

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Operating at EUV wavelengths, the SEMATECH Berkeley Actinic Inspection Tool (AIT) is a zoneplate microscope that provides high quality aerial image measurements in routine operations for SEMATECH member companies. We have upgraded the optical performance of the AIT to provide multiple image magnifications, and several inspection NA values up to 0.35 NA equivalent (0.0875 mask-side). We report on the improved imaging capabilities including resolution below 100-nm on the mask side (25 nm, 4× wafer equivalent).

EUV reticles are intricate optical systems made from of several materials with wavelength-specific optical properties. The combined interactions of the substrate, multilayer-stack, buffer layer and absorber layer produce a reflected EUV optical field that is challenging to model accurately, and difficult to fully assess without actinic *at-wavelength* inspection. Understanding the aerial image from lithographic printing alone is complicated by photoresist properties.

The AIT is now used to investigate mask issues such as amplitude and phase defect printability, pattern repair techniques, contamination, inspection damage, and mask architecture. The AIT has a 6° illumination angle, and high-resolution exposure times are typically 20 seconds per image. The AIT operates semi-automatically capturing through-focus imaging series with step sizes as small as 0.1 µm (0.5–0.8 µm are typical), and a step resolution of 0.05 µm. We believe it is the most advanced EUV mask inspection tool in operation today.

In the AIT, an EUV image of the mask is projected by a zoneplate lens with high magnification (680–910×) onto a CCD camera. The CCD over-samples the image, providing equivalent pixel sizes down to 15 nm in mask coordinates—several image pixels per resolution element. The original AIT zoneplate specifications were designed to emulate the resolution of a 0.25-NA 4× stepper, and thorough benchmarking analysis of the aberrations, flare, contrast-transfer function, and coherence was published in 2007 [1] (see Fig 1).

Recent upgrades have also included changes to improve the illumination uniformity and increase the partial coherence σ value. Five different zoneplate lenses are installed side-by-side to enable the AIT to emulate various stepper optical properties (see Fig. 2). Supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Keywords: EUV, actinic, mask inspection, reticle, EUV, zoneplate, aerial image

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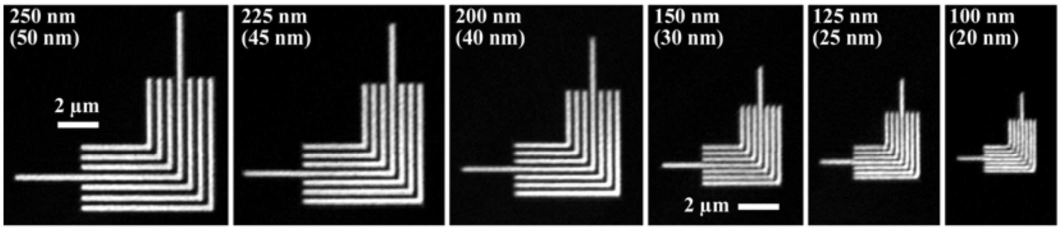

Fig 1. Representative 0°-90° elbow patterns from 0.0625-NA benchmarking. These images were among several hundred used in the calculation of the dark-field CTF. The mask half-pitch values are given for each image; 5× equivalent wafer size values are shown in parentheses. A finite astigmatism magnitude makes the contrast different in the two directions shown. All images are on the same size scale.

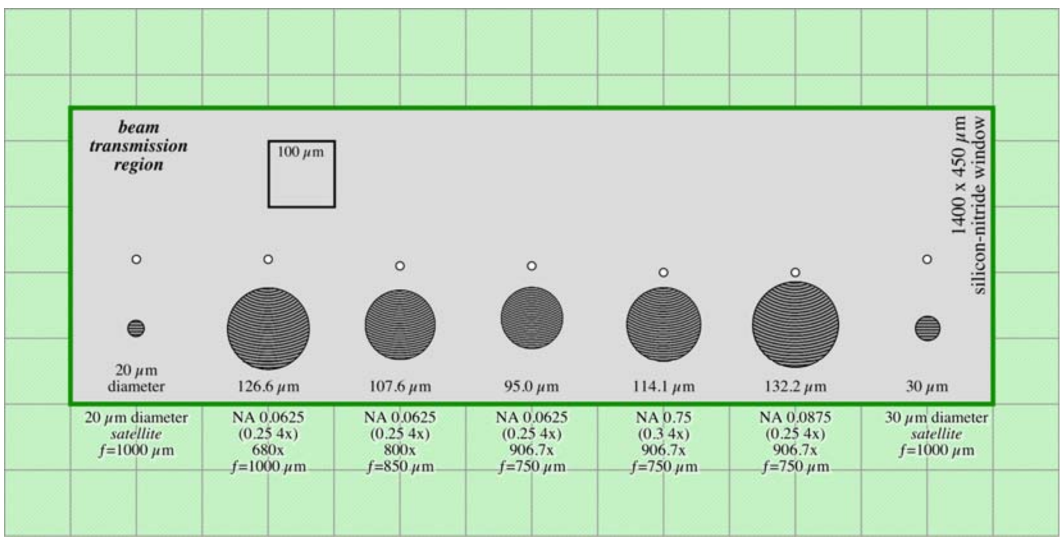

Fig 2. Schematic representation of the new multi-zoneplate design. Five off-axis zoneplates are arrayed side-by-side on a silicon nitride membrane that is parallel to the mask surface, and approximately 1 mm above the mask. The zoneplates are used one at a time. Two additional *satellite zoneplates* at either end are used for alignment. When aligned, the 6° incident beam, which has comparable size to the area occupied by a single zoneplate, passes through the open membrane area shown above the zoneplates in the figure. The central ray of the reflected beam hits the center of the zoneplate pupil. The off-axis design directs the focused first-order beam vertically, while the other orders propagate at different angles and do not reach the CCD camera. Approximately 17 mm above the zoneplate membrane, a multilayer-coated flat 45° turning mirror re-directs the beam into the horizontal plane to the CCD camera which is 660 mm away. The small white circles indicate the center of the full parent zoneplate design and are positioned directly above the illuminated position on the mask. Their slight vertical displacement is required to accommodate the circular shape of the turning mirror.