Extreme ultraviolet mask substrate surface roughness effects on lithographic patterning

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Pattern resolutions of 16 nm or better are becoming the requirement for advanced lithography. The candidate technology at the forefront for high volume manufacturing is extreme ultraviolet (EUV) lithography, which utilizes an all reflective optical system and a patterning wavelength near 13.5 nm. In order to achieve high reflectivity for this wavelength, the optics and the reflective photomask exploit thin film interference properties with 40 or more alternating thin layers of Molybdenum and Silicon deposited on a substrate. A considerable problem for the mask and the optics at this illuminating wavelength is roughness-induced multilayer scattering. It is well known that this scattering leads to throughput loss in the optical system and reduced image contrast due to flare at the image plane. This loss in contrast can lead to reduced exposure latitude and indirectly cause increased line-edge roughness (LER). Of more recent concern, however, is how such roughness present on the mask may directly lead to LER through the formation of speckle in the patterned image.

Recent modeling studies have shown that mask multilayer roughness must be limited to 50 picometers to meet current LER targets for the 22 and 16-nm half-pitch lithography nodes [1]. The roughness of most concern, however, is that which is phase coherent from layer to layer bringing into question the suitability of top-surface roughness analysis methods such as Atomic Force Microscopy (AFM) for its characterization. Because the root cause of LER from phase coherent roughness is speckle in the aerial image, to develop accurate mask specifications and suitable roughness metrics it is crucial to understand the relationships between bottom (substrate) surface roughness, top surface roughness, EUV scattering, and aerial image speckle.

In this presentation, we explicitly study the impact of substrate roughness on image plane speckle. Moreover, we quantify the extent to which an AFM measurement can be depended upon for specifying tolerable roughness limits on EUV masks and demonstrate an alternative metrology method capable of directly measuring phase-coherent roughness. Design of the study involved a mask prepared with areas of varying roughness that was then deposited with Mo-Si multilayers. AFM based topography was collected for each area before and after multilayer deposition. Figure 1 shows two AFM surface measurement, where the image on the left (A.) is an area with low roughness and the image on the right (B) is the area with the highest roughness. The sample areas were then imaged with the SEMATECH Berkeley Actinic Inspection Tool (AIT) which is a zoneplate microscope for EUV mask inspection [2], thus, directly characterizing the aerial image speckle. The corresponding EUV microscope images to the AFM image areas are shown in figure 2. The same mask sample was then subjected to EUV reflectometry and scattering measurements to obtain phase-coherent roughness parameters. Figure 3 shows scattering data collected from the mask along a row of rectangular areas programmed with increasing roughness. Wavelength of light used was 13.46 nm at a 5 degree angle of incidence. Finally, modeling is used to test the effectiveness of the two different roughness metrologies in predicting the measured aerial-image speckle.

1. Implications of image plane line-edge roughness requirements on extreme ultraviolet mask specifications, Patrick P. Naulleau and Simi A. George, Proc. SPIE 7379, 73790O (2009)
2. K. A. Goldberg, I. Mochi, P. P. Naulleau, H.-S. Han, S. Huh, "Benchmarking EUV mask inspection beyond 0.25 NA,"SPIE Photomask (BACUS) 7122, 71222E-1 (2008)

Figure 1: AFM measured surfaces after multilayer deposition; (A, left) is the image of an area with low roughness and the image on the right (B) is the area with the highest roughness.

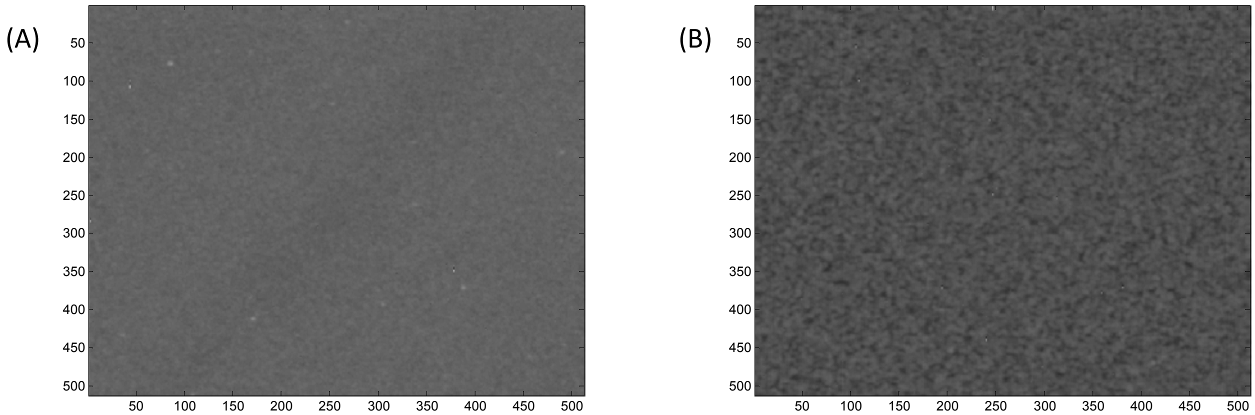

Figure 2: Images obtained with the Sematech Berkeley AIT EUV microscope for the areas shown in figure 1, at best focus of the 0.3NA zone plate lens.

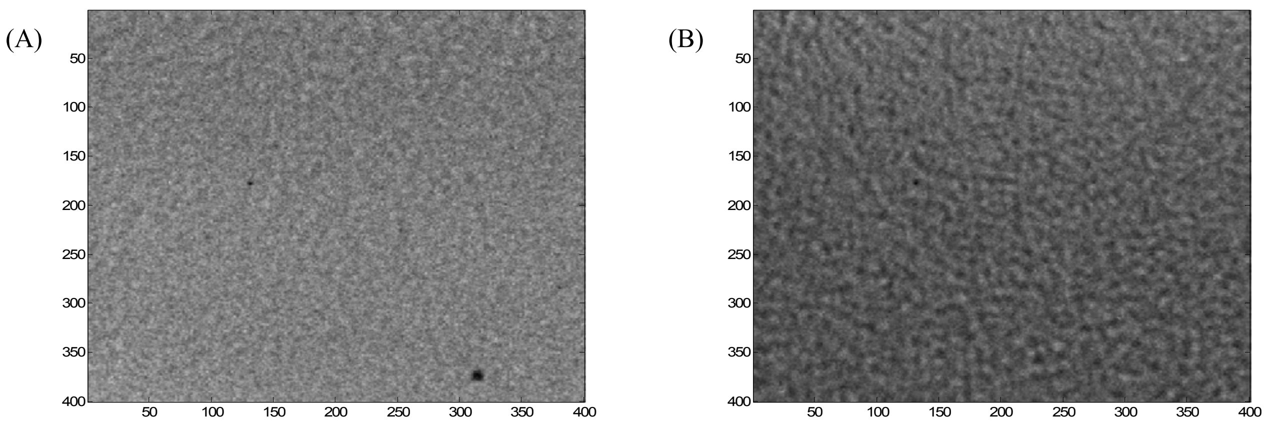

Figure 3: Raw EUV scattering data collected for a row of varying roughness areas on the mask sample. As the roughness increases, strong scattering is observed for the wavelength of 13.46 nm at 5 degrees angle of incidence.