Characterization of Telecentricity Errors in High-Numerical-Aperture Extreme Ultraviolet Mask Images

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Non-telecentric illumination of the mask in extreme ultraviolet (EUV) lithography leads to through-focus image shifts at the wafer referred to as telecentricity errors (see Fig. 1). As the industry begins to use higher-numerical-aperture (NA) EUV imaging systems to improve resolution, the effect of telecentricity errors will become more significant since telecentricity errors are dependent on pattern pitch, pattern type, lens aberrations, mask film stack, and illumination conditions. In this paper, we present a novel technique to determine telecentricity errors from EUV mask images captured with the SEMATECH High-NA Actinic Reticle Review Project (SHARP) tool[1] at Lawrence Berkeley National Laboratory. SHARP can image EUV masks at different numerical apertures including NA >0.33 (high-NA EUV) and with a number of different (programmable) illumination modes.

We developed an EUV mask on a blank with a 51 nm thick Ta-based absorber and a custom Mo/Si reflective coating designed to compensate telecentricity errors at the resolution limit of 0.41 NA.[2] The mask absorber was patterned at AMTC-Dresden with dedicated test structures to quantify telecentricity errors from through-focus images captured with SHARP via custom image post processing software. Images were captured at a variety of NA and illumination settings. A comparison between measurement and rigorous mask 3D simulation of the pattern shift of 32 nm pitch lines and spaces imaged at 0.35 NA with conventional illumination and 6^{o} chief-ray-angle (CRA) is shown in Fig. 2 and a comparison of pattern shifts of 32 nm pitch horizontal lines captured at 0.35 NA and 6^{o} CRA and at 0.50 NA and 8^{o} CRA is shown in Fig. 3.

In the talk, we will discuss the first experimental proof of telecentricity errors in high NA EUV imaging from the mask perspective. Furthermore we will report on methods to separate SHARP tool imaging artifacts from the mask stack contributions to telecentricity errors.

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[1] K.A. Goldberg, et al., "Commissioning a EUV mask microscope for lithography generations reaching 8 nm," Proc. SPIE 8679, 867919 (2013).
[2] V. Philipsen, et al., "Impact of mask stack on high NA EUV imaging," 2012 International Symposium on Extreme Ultraviolet Lithography, Brussels, Belgium, 30 Sept - 4 Oct 2012.

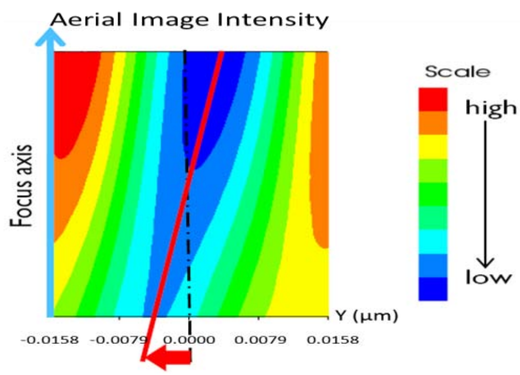

Figure 1 – Aerial image intensity versus focus for a simulated 0.33 NA EUV image of horizontal lines and spaces produced with dipole-Y illumination illustrating a pattern shift with respect to the focus axis due to telecentricity error.

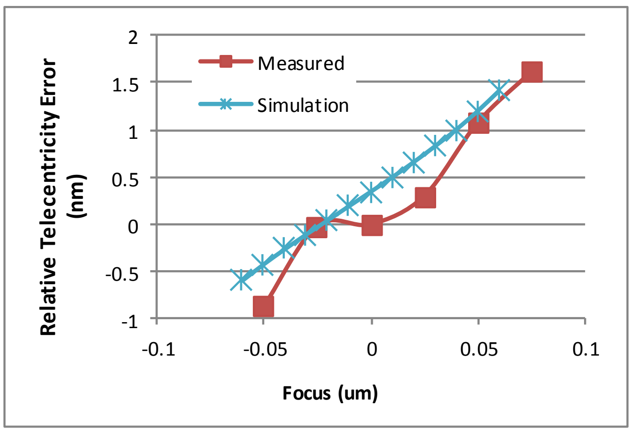

Figure 2 – Comparison of pattern shift of 32 nm pitch lines and spaces imaged at 0.35 NA and 6^{o} CRA with conventional illumination from rigorous mask 3D simulation and measurement using the SHARP tool in Berkeley.

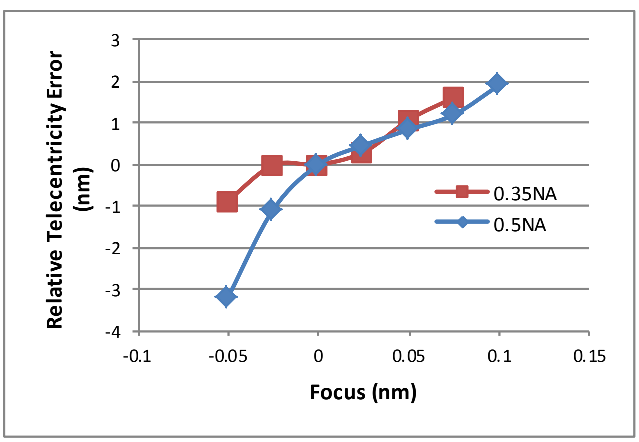

Figure 3 – Measurements of through-focus shifts of 32 nm pitch horizontal lines from actinic EUV images produced with conventional illumination captured at 0.35 NA and 6^{o} CRA and at 0.50 NA and 8^{o} CRA.