Actinic imaging and evaluation of phase structures on EUV lithography masks

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In EUV lithography, the phase of the reflected light field from multilayer-coated reflective reticles is sensitive to buried patterned structures and imperfections in the multilayer and substrate. Currently, these phase effects are particularly difficult to quantify using non-EUV inspection techniques and printing into photoresist. Through-focus EUV mask images recorded using a high-resolution EUV-wavelength microscope can sensitively reveal the magnitude of such phase structures through variations in the observed intensity profiles.

We operate the SEMATECH Berkeley Actinic Inspection Tool (AIT), a synchrotron-based EUV microscope designed for mask inspection that works with nearly coherent illumination, with σ values below 0.2, at 13.4-nm wavelength. The high-coherence properties of the AIT enhance its sensitivity to phase structures.

In this paper we describe how through-focus EUV mask images recorded with the AIT are used to evaluate the severity and importance of programmed and native phase structures, including bump and pit-type defects on a blank mask, and buried-pattern phase-structures on a prototype EUV phase-shifting mask.

Images of phase structures reveal signature through-focus effects. At EUV wavelengths, a defect with a height of approximately 4 nm can produce a nearly lossless π phase change. Therefore even the native roughness of the substrate can propagate through the multilayer and create an intensity contrast pattern that significantly affects the quality of the image. [1] The native roughness that appears on all masks contributes to observed or printed pattern roughness, and affects the detection sensitivity of the AIT in ways that we can quantify.

We compare through focus image series of different phase structures to simulated images to extract information about their equivalent phase and size, and to assess the AIT's detection limits for isolated phase defects.

[1] P. P. Naulleau, *et al.*, *Proc. SPIE* **7271**, 7271-0W, (2009).

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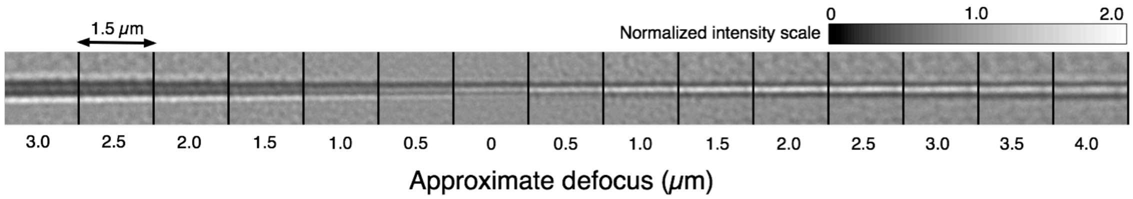

Figure 1. Through focus image series of a buried 250-nm (mask size) line collected with the AIT. In this image it is possible to see the through focus intensity evolution of a phase line. Note the change in intensity in the central section of the line from one side of focus to the other. The mask's inherent phase roughness is also evident in the through focus series.

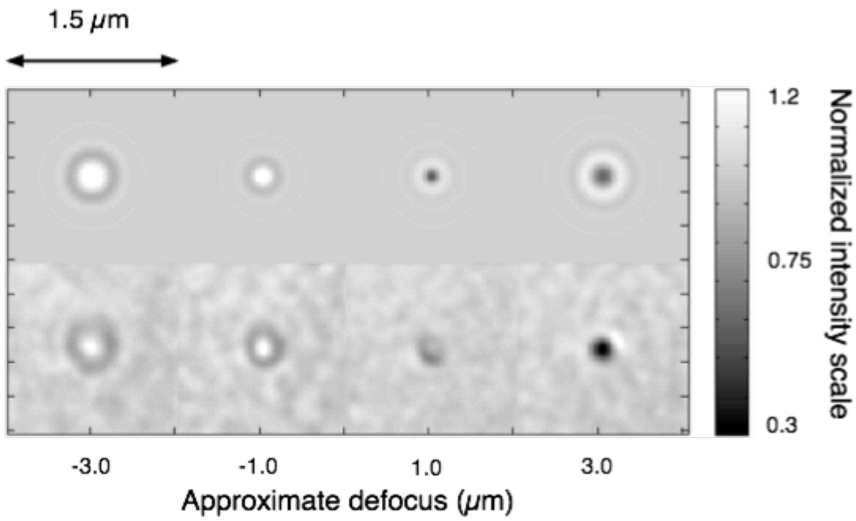

Figure 2. The lower panel shows measured images of a native bump-like phase defect on a blank mask. The upper panel shows a simulation of such a defect. Near best focus, the central intensity value of a bump-type phase defect decreases through focus.

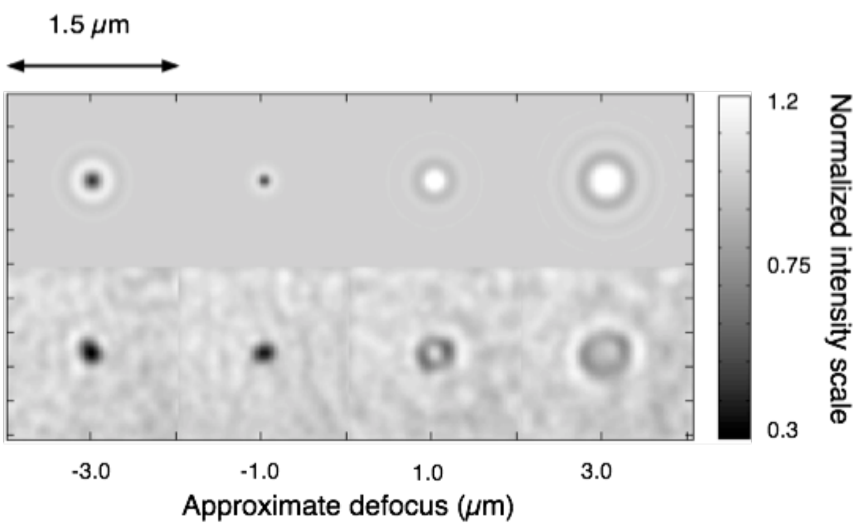

Figure 3. The lower panel shows images of a measured native pit-like phase defect on a blank mask. The upper panel shows a simulation of such a defect. Near best focus, the central intensity value of a pit-type phase defect increases through focus.