Implications of image plane line-edge roughness requirements on extreme ultraviolet mask specifications

Patrick P. Naulleau and Simi A. George
Center for X-Ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA 94720
Phone: 510-486-4529 e-mail: PNaulleau@lbl.gov

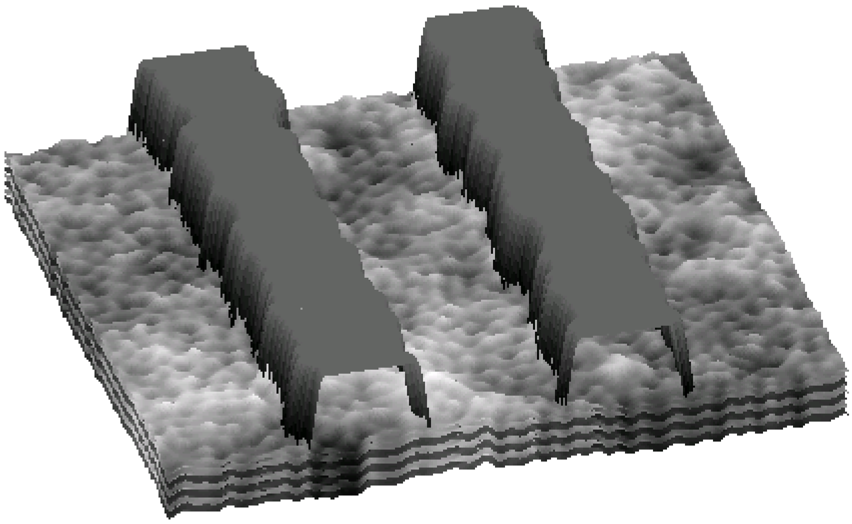
Line-edge roughness (LER) and the related effect of contact size variation remain as significant challenges facing the commercialization of extreme ultraviolet (EUV) lithography. LER is typically viewed as a resist problem; however, recent simulation results have shown that the mask can indeed be an important contributor. Problems arise from both mask absorber LER as well as mask multilayer roughness leading to random phase variations in the reflected beam (see Fig. 1). The latter effect is especially important as higher coherence off-axis illumination conditions are used and defocus is considered.

Here we describe these effect in detail and explore how they will impact EUV mask requirements for the 22-nm half-pitch node and beyond. Figure 2 shows modeling results for 22-nm lines printed in a 0.32-numerical aperture system with 100-nm defocus assuming a mask with 0.24-nm rms multilayer roughness and no absorber edge roughness (unlike the example in Fig. 1). The impact of the phase roughness on the printed line-edge roughness is clearly evident and demonstrates the basic problem with mask roughness.

The more detailed modeling-based analysis to be presented will account for performance throughout the process window as well as non-stochastic resist effects. We note that the mean-field resist effect is important to consider because, in practice, the resist is the limiting resolution element in the system and therefore dominates the mask-error enhancement factor (MEEF). As is typically the case with projection-optic-induced MEEF, the resist-induced MEEF will lead to even tighter mask requirements. Note that we do not consider resist stochastic effects since the purpose of this study is isolate mask-induced sources of image-plane roughness.

This work was supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Fig. 1. Example of mask with both absorber edge and reflector phase roughness



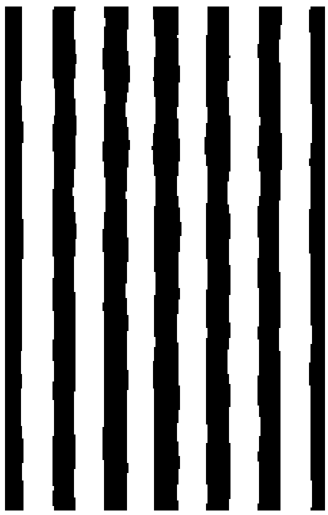


Fig. 2. Example of the effect of mask multilayer roughness on printed 22-nm lines. The modeling results assume an aberration free optic with a numerical aperture of 0.32 and a defocus of 100 nm. Moreover, the mask multilayer roughness is assumed to be 0.24 –nm rms and the absorber lines are assumed to be perfectly smooth (unlike the