Mask topography induced phase effects and wave aberrations in optical and EUV lithography

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Abstract:

Rigorous electromagnetic field (EMF) simulation of light diffraction from advanced lithographic masks has become an established technique for the predictive simulation of advanced lithographic processes using optical or EUV projection lithography. Different EMF solvers are applied to investigate mask topography effects in terms of diffraction efficiencies, projected images, and lithographic process windows. So far, little attention has been given to the phase of the diffracted light.

The transmission/reflection of light through/from a mask absorber feature modifies both the intensity and the phase of the light which contributes to the image formation. Phase shift masks (PSM) make use of the phase modulation to improve the resulting image in terms of contrast, slope or other criteria. Rigorous EMF simulation of light transmission/reflection though/from masks predicts a local variation of the phase – even in the case of a nominal binary mask. The deviation between the rigorously simulated phase and the "designed" phase can be considered as mask topography induced phase deformation. The resulting phase deformation depends on the geometry and optical material properties (refractive index n and extinction k) of the absorber. It increases with decreasing feature sizes and with increasing absorber thickness. The large ratio between the absorber thickness and wavelength makes EUV masks very sensitive to such phase deformations. Similar statements apply to alternating or chromeless optical masks.

The described phase deviation can be also analysed in the far field of the mask or at the entrance pupil of the projection lens. Therefore, we define the phase deformation as the difference between the phase of rigorously simulated diffraction orders and the phase of diffraction orders which are obtained from an idealized mask. The resulting phase deformation of all diffraction orders which enter the projection pupil is fitted by Zernike polynomials. The described Zernike analysis of the wavefront of the diffracted light can be used for an efficient study of the impact of mask and illumination parameters on the mask induced imaging artefacts.

The mask topography induced phase deformation results in several typical wave aberration induced imaging phenomena such as feature size and orientation dependent shifts of the best focus position, tilted process windows, and placement errors. Such effects can be observed both for optical and EUV masks. However, there is an important difference between mask and projector pupil induced phase deformations. The projector wave aberrations are fixed to the lens pupil. In contrast to that, mask induced phase deformations are fixed to specific diffraction orders and weighted by their intensity. Extensive simulations are used to study the impact of the mask induced phase deformations on typical lithographic process parameters. The magnitude of the observed effects depends on absorber material/geometry, stepper parameters, and photoresist performance.

Figures:

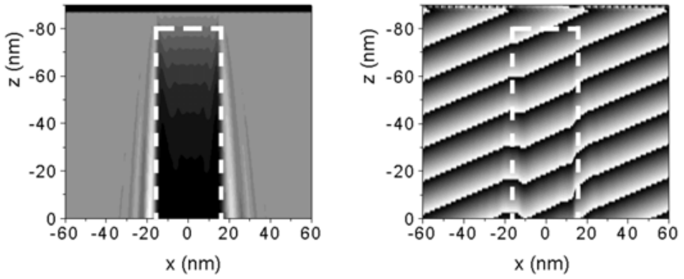

Figure 1: Simulated intensity (left) and phase (right) of the electromagnetic field in the vicinity of a 80nm thick and 30nm wide Cr absorber on a EUV mask, λ=13.5nm, light incidence from the upper left.

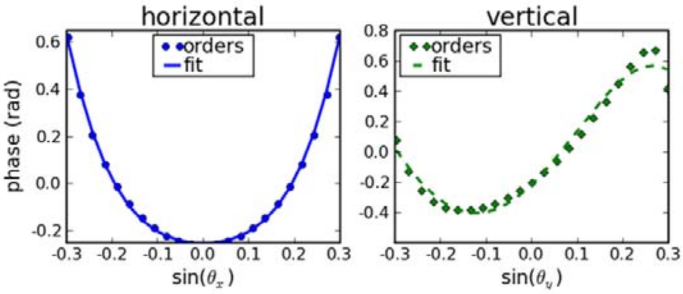

Figure 2: Far field analysis of the phase deformation of a EUV mask with 32nm wide and 80nm thick Cr absorber lines (pitch = 500nm) for different orientation of the lines. θ_x – diffraction angle.

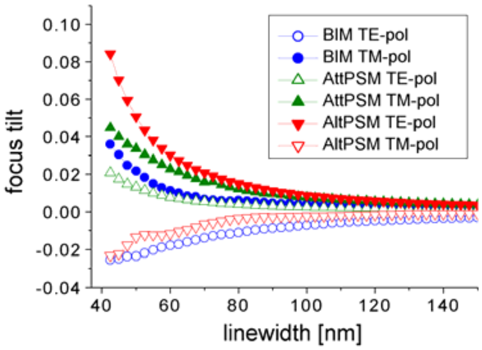

Figure 3: Simulated focus tilt (ΔCD/Δfocus @ best dose and focus) for the imaging of semi-dense lines with different optical mask types versus linewidth/NA for a constant k_1=0.3, λ=193nm. a) BIM: 80nm thick chromium absorber, annular illumination σ=0.55/ 0.85, b) 6% AttPSM 68nm thick MoSi-absorber, annular illumination σ=0.55/0.85, c) AltPSM: 80nm thick chromium absorber, circular illumination σ=0.3.

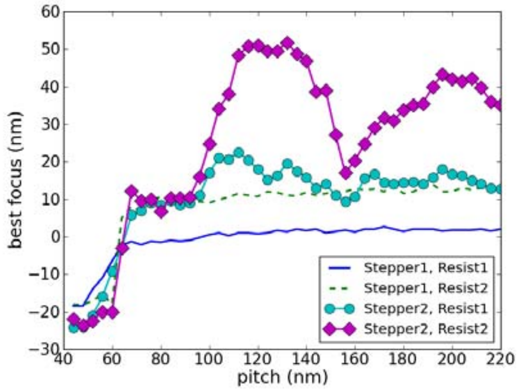

Figure 4: Simulated best focus position of 22nm lines versus pitch for different EUV-steppers and photoresists, 80nm thick Cr absorber, both steppers are assumed to be aberration free, but differ in NA and illumination settings, the two photoresists differ in diffusion lengths of acid and quencher, respectively.