

LER Control and Mitigation: Mask Roughness Induced LER



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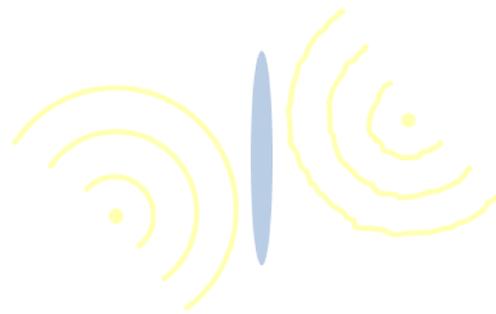
Aberrations sensitivity study and alternate illumination scheme

Control and Mitigation

In the push towards commercialization of extreme-ultraviolet lithography (EUVL), meeting the stringent requirements for line-edge roughness (LER) is increasingly challenging. For the 22-nm half-pitch node and below, the ITRS requires under 1.2 nm LER.

Much of this LER is thought to arise from three significant contributors: LER on the mask absorber pattern, LER from the resist, and LER from mask roughness induced speckle. The physical mechanism behind the last contributor is becoming clearer, but how it is affected by the presence of aberrations is less well understood.

Here, we conduct a full 2D aerial image simulation



Aberrated imaging distorting wavefronts.

analysis of aberrations sensitivities of mask roughness induced LER for the first 37 fringe zernikes. These results serve as a guideline for future LER aberrations control.

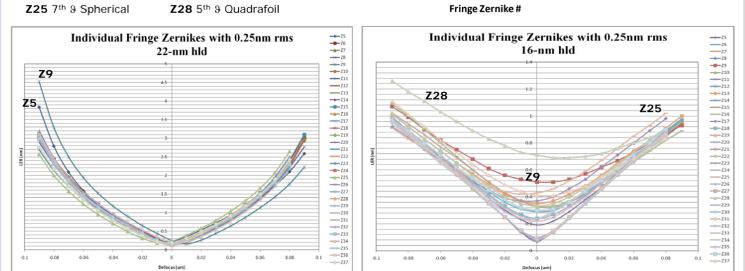
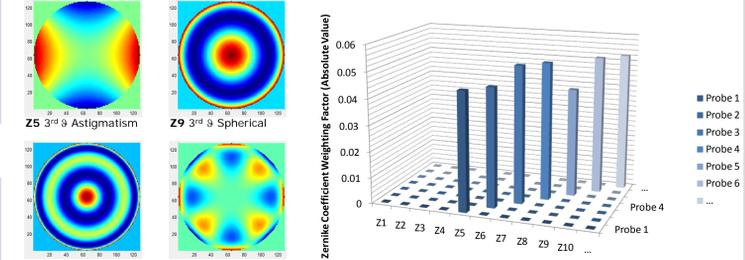
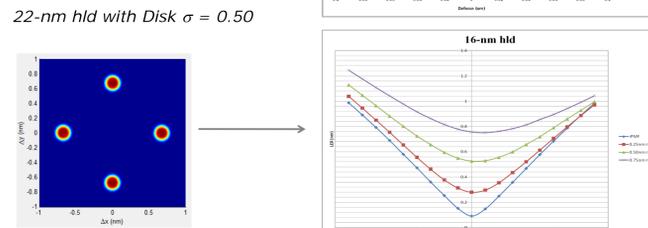
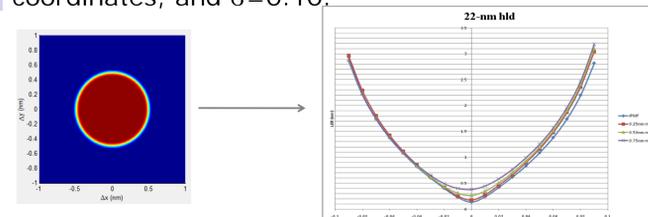
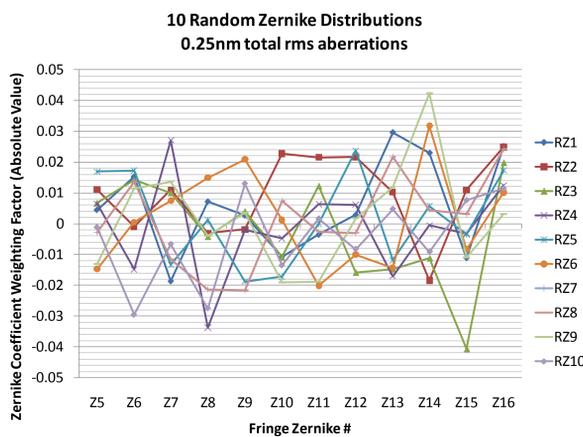
In examining how to mitigate mask roughness induced LER, we next consider an alternate illumination scheme whereby a traditional dipole's angular spectrum is extended in the direction parallel to the line-and-space mask absorber pattern to represent a "strip". While this illumination surprisingly provides merely minimal improvement to the LER as several alternate illumination schemes, overall imaging quality in terms of ILS, NILS, and contrast is improved.

Aberrations Sensitivity Matrix

In our aberrations study, we consider a system with NA=0.32, smooth lines and spaces (22- and 16-nm half-pitches), a rough mask with replicated surface roughness (RSR) of 100pm, and correlation length of the roughness at 32nm, all with standard illumination wavelength of 13.5nm.

For the 22-nm half-pitch, illumination we looked at a disk with partial coherence factor $\sigma=0.50$, and for the 16-nm half-pitch, a crosspole properly displaced to $dx=0.67$, $dy=0$ in normalized pupil coordinates, and $\sigma=0.10$.

We then constructed an aberrations sensitivity matrix through focus for all first 37 fringe zernikes (again, ignoring the first four), whereby all the rms aberration amount (0.25, 0.50, 0.75nm rms) is concentrated singly in one fringe zernike at a time. These results serve as a guideline for future mask roughness induced LER control, in the presence of aberrations.



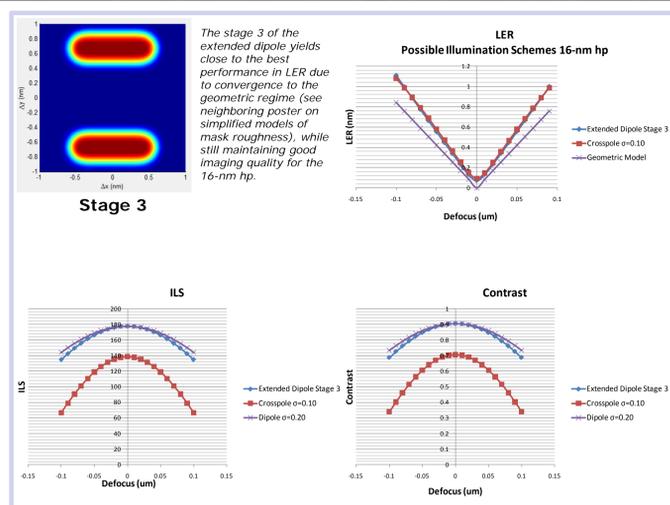
We first consider 10 random zero-mean distributions for three aberration levels (0.25, 0.50, 0.75nm total rms) amongst the first most important 16 fringe zernikes, ignoring the first four (piston, x-tilt, y-tilt, and power).

Results show that in order to maintain the requirements in total LER for the 22-nm half-pitch nodes and beyond, aberration tolerance seems to extend at most to the 0.25nm total rms level.

Extended Dipole "Strip" Illumination

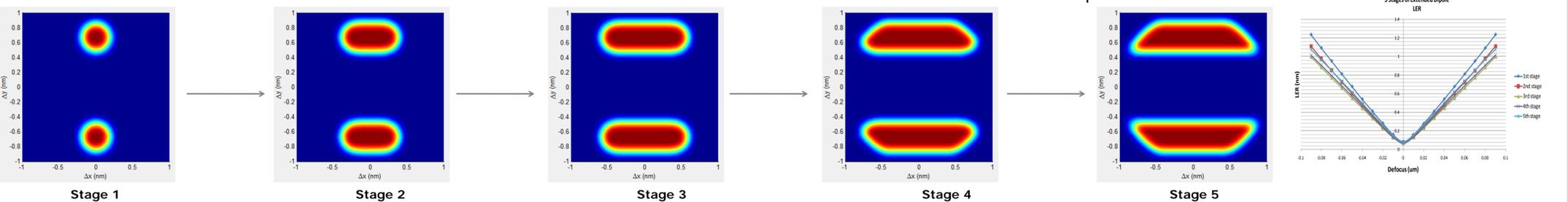
In examining how to mitigate the consequences of mask roughness induced LER, we next consider an alternate illumination scheme, whereby a traditional dipole's angular spectrum is extended in the direction parallel to the line-and-space mask absorber pattern to represent a "strip", for the 16-nm half-pitch. The stretch was done in five stages, gradually extending the dipole a little further each stage.

This reduction in coherence in direction parallel to the predominant pattern orientation should effectively reduce the speckle arising from mask roughness, while the high coherence in the orthogonal direction should maintain good resolution and high image-log-slope, indicative of good imaging quality.



We looked at results for an aberration-free system with NA=0.32, smooth 16-nm lines and spaces, a rough mask with RSR of 100pm, and correlation length of the roughness at 32nm, properly displaced dipole settings of $dx = 0.67$ and $\sigma = 0.20$, and illumination wavelength of 13.5nm.

Below, it is seen that the stage 3 extended dipole yields an improvement of ~0.2nm mask roughness LER at the extrema of focus, compared to conventional dipole illumination. The LER improvement seems to stop as the pupil starts clipping the strip. Results to the left show that while the stage 3 provides nearly the same LER as the crosspole illuminations considered above, overall imaging quality in terms of ILS, NILS, and contrast is improved.



Results

While the 22-nm half-pitch node can tolerate significant aberrations from a mask roughness induced LER perspective, total aberration levels for the 16-nm half-pitch node need to be strictly capped at 0.25nm rms to meet the ITRS guidelines.

An individual aberrations study for the first 37 fringe zernikes on the 16-nm half-pitch node at the 0.25nm rms level reveals a sensitivity to various forms of spherical aberrations (Z9 & Z25) and quadrafoil (Z28) in particular, under conventional crosspole illumination ($\sigma = 0.10$).

Compared to conventional dipole or crosspole illuminations, an extended dipole "strip" illumination scheme offers a way to mitigate mask roughness induced LER, while still maintaining high imaging quality for critical mask levels at the 16-nm half-pitch node.

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