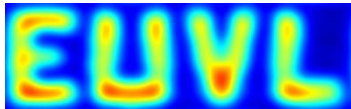




Experimental verification of phase induced mask 3D effects in EUV imaging

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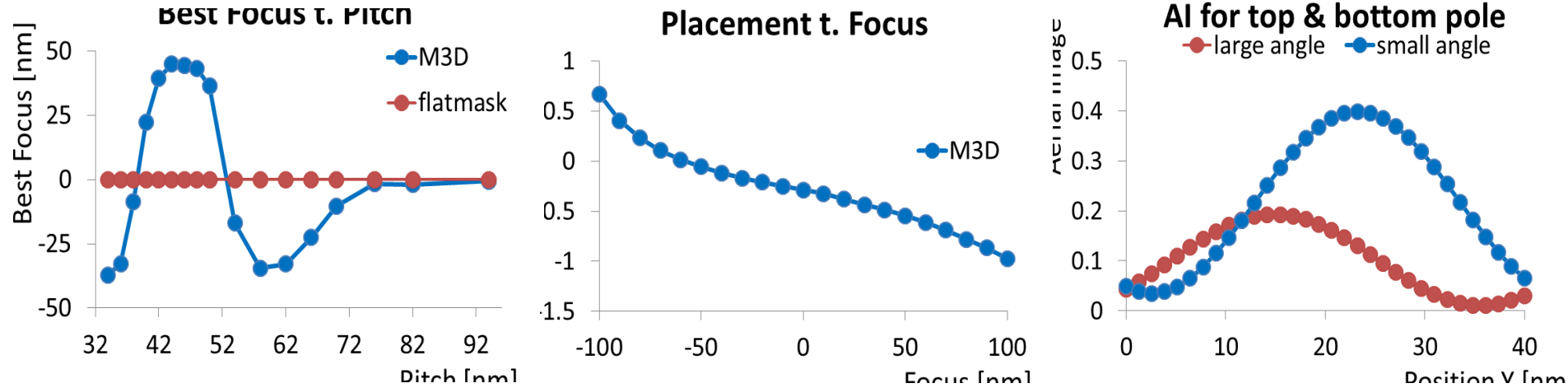
- **M3D – angular illumination and the 3D EUV reticle**
 - Best focus shifts, pattern shift, contrast loss
 - Phase shifts in the diffracted orders
 - M3D effects for extended illumination pupils
- **Experimental verification**
 - Pattern shift through focus
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Mask 3D effects – challenges for EUV lithography

The 3D EUV mask diffraction amplitudes and phases are very different from the diffraction for an ideal 2D mask. As a result, the imaging of a real EUV mask is very different from the idealized 2D mask case.

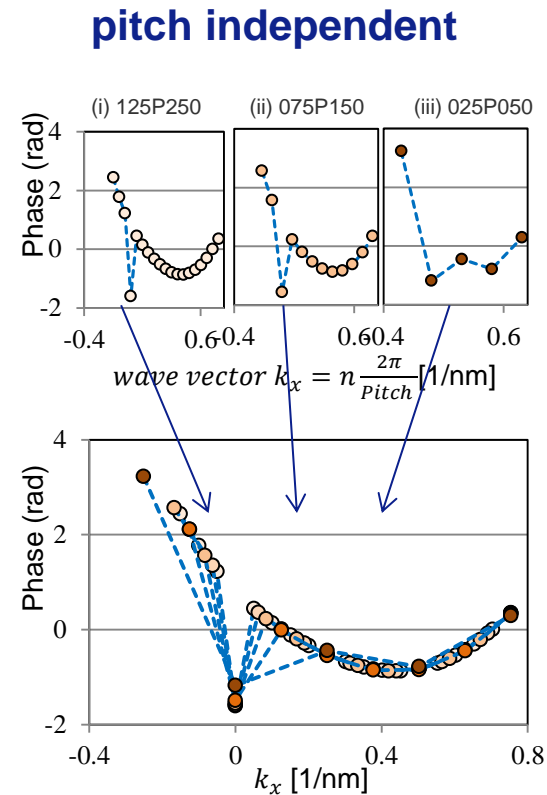
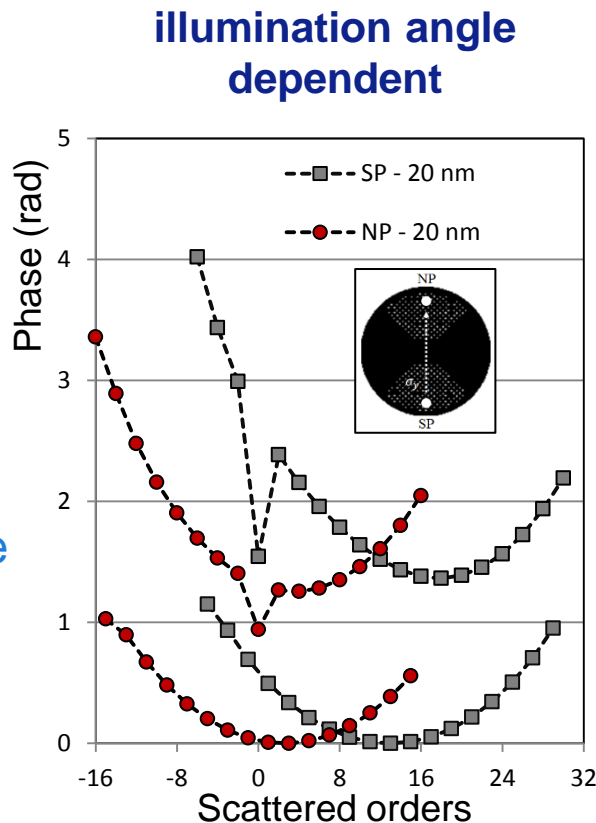


The pronounced differences (or challenges) for EUV imaging are often referred to as 'mask 3D effects'. These include best focus shifts through pitch, pattern shift through focus and fading induced contrast loss.

Phase shifts in the diffracted orders @ the EUV mask

To go a level deeper into the M3D effects for EUV, phase of the diffracted orders is assessed in literature.^{1,2}

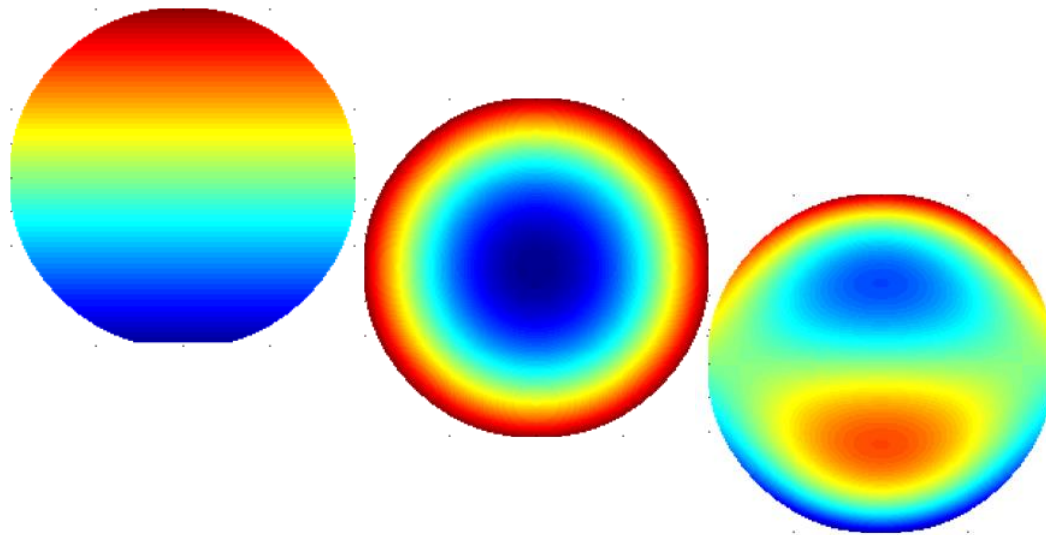
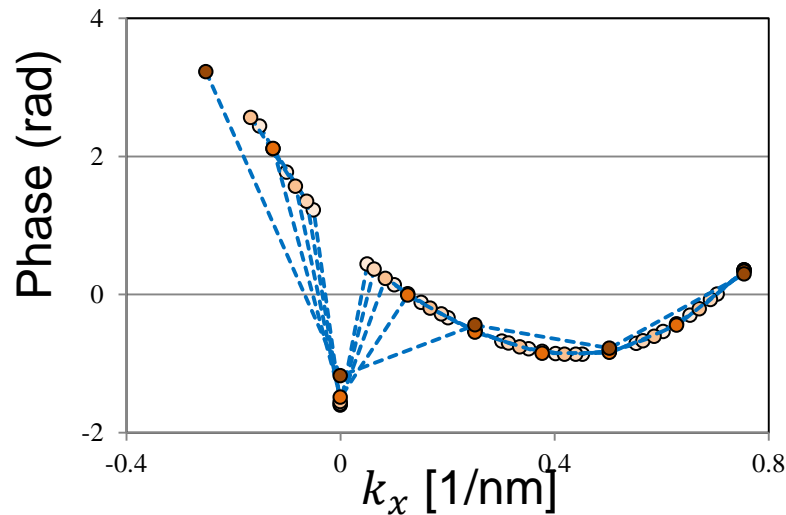
Mapping diffraction order phase on the position in the pupil plane shows that phase shifts are **dependent on illumination angle** and **independent of the pitch**.



¹ L. de Winter, EMLC 2015 ² T. Last, BACUS 2015

Phase shifts in the diffracted orders @ the EUV mask

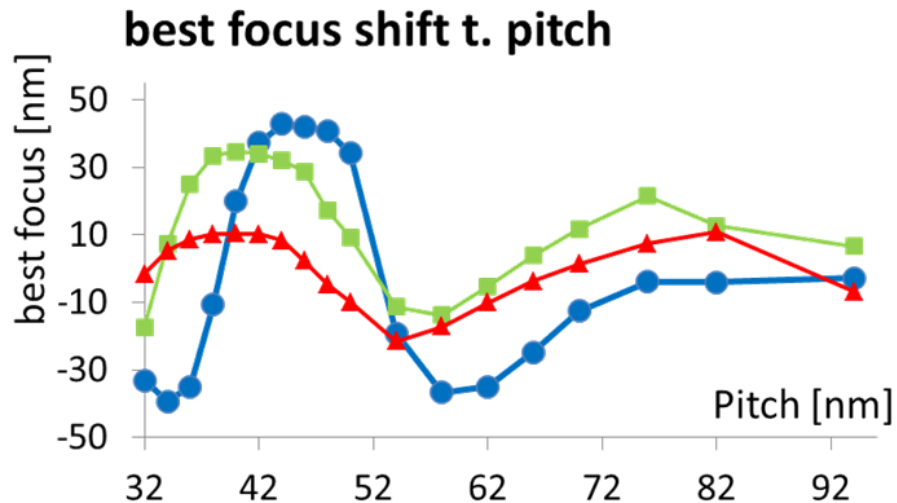
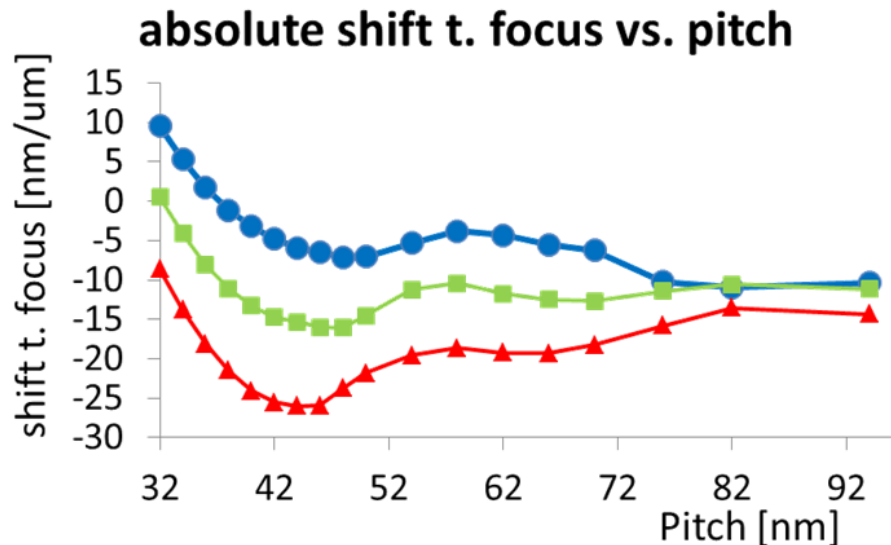
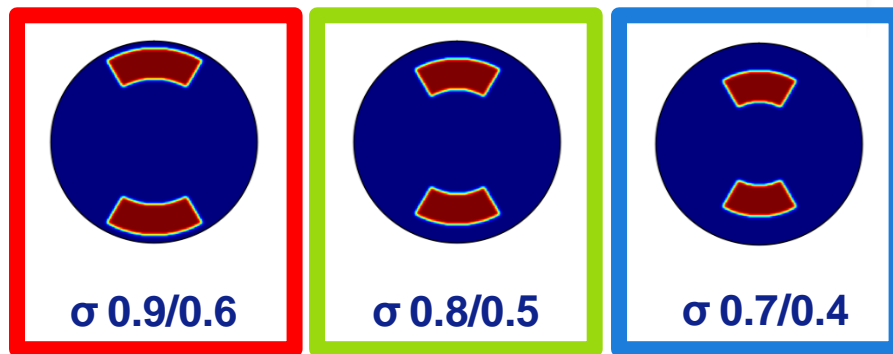
Phase in the pupil plane is usually expressed in Zernike fringe polynomials.



A limited set of coma and spherical terms covers the relevant odd and even orders. In analogy with lens Aberrations the coma terms explain placement and contrast effects and the spherical terms explain focus and contrast effects.

M3D effects for extended illumination pupils

Best focus through pitch and pattern shift through focus for three dipole illumination pupils, predicted by simulations.

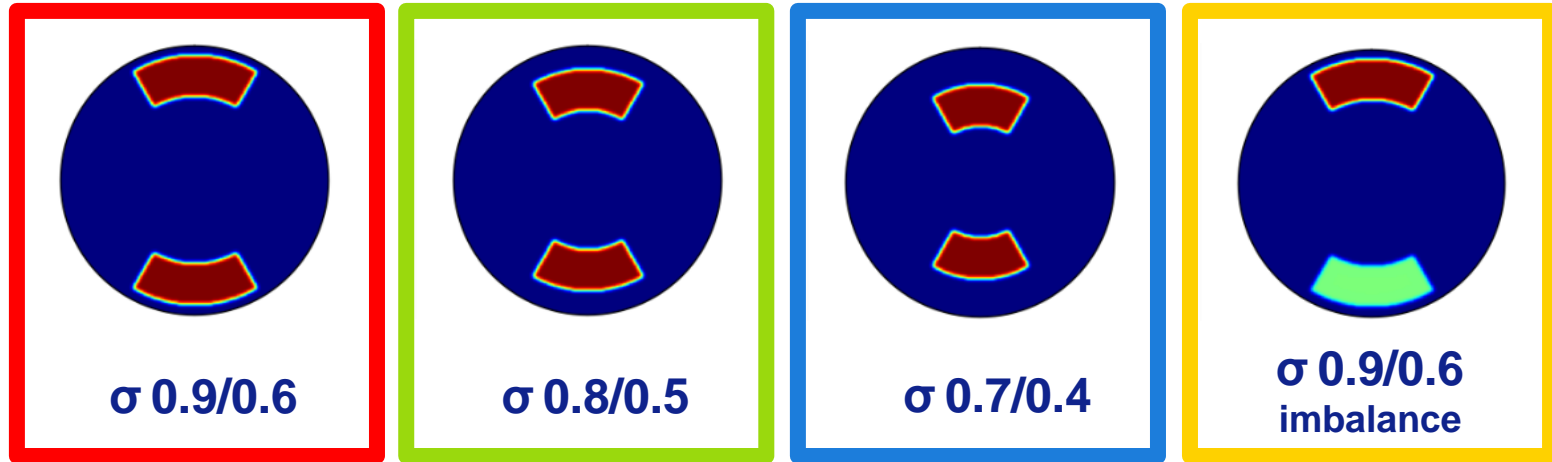


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Experimental verification of the simulated effects

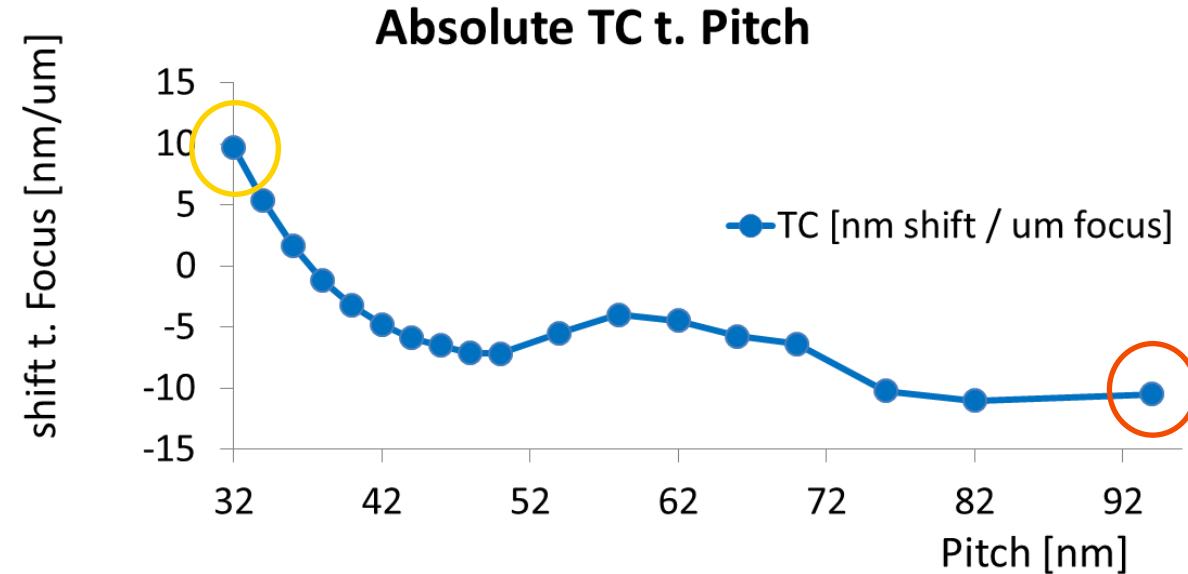
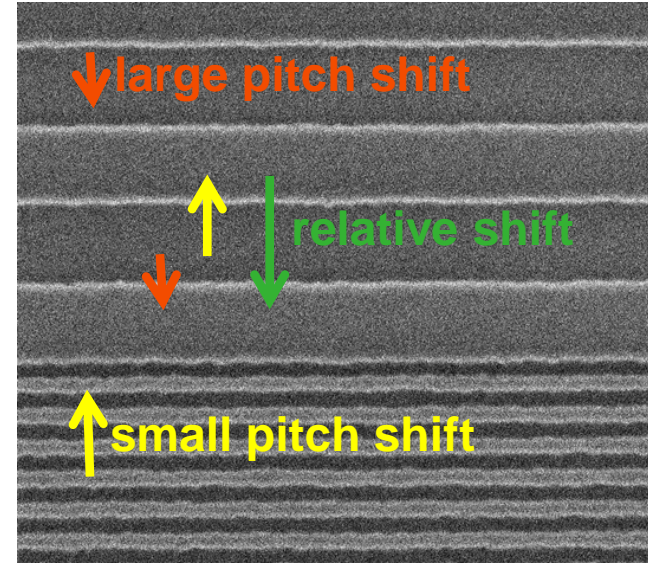
For verification of trends in placement and best focus for variations in the illumination angles, 4 wafers are exposed on a NXE:3300 EUV scanner using 4 dipole-Y illumination pupils.



Experimental verification for pattern shift through focus and best focus shift through pitch.

Pattern shift through focus – experimental method

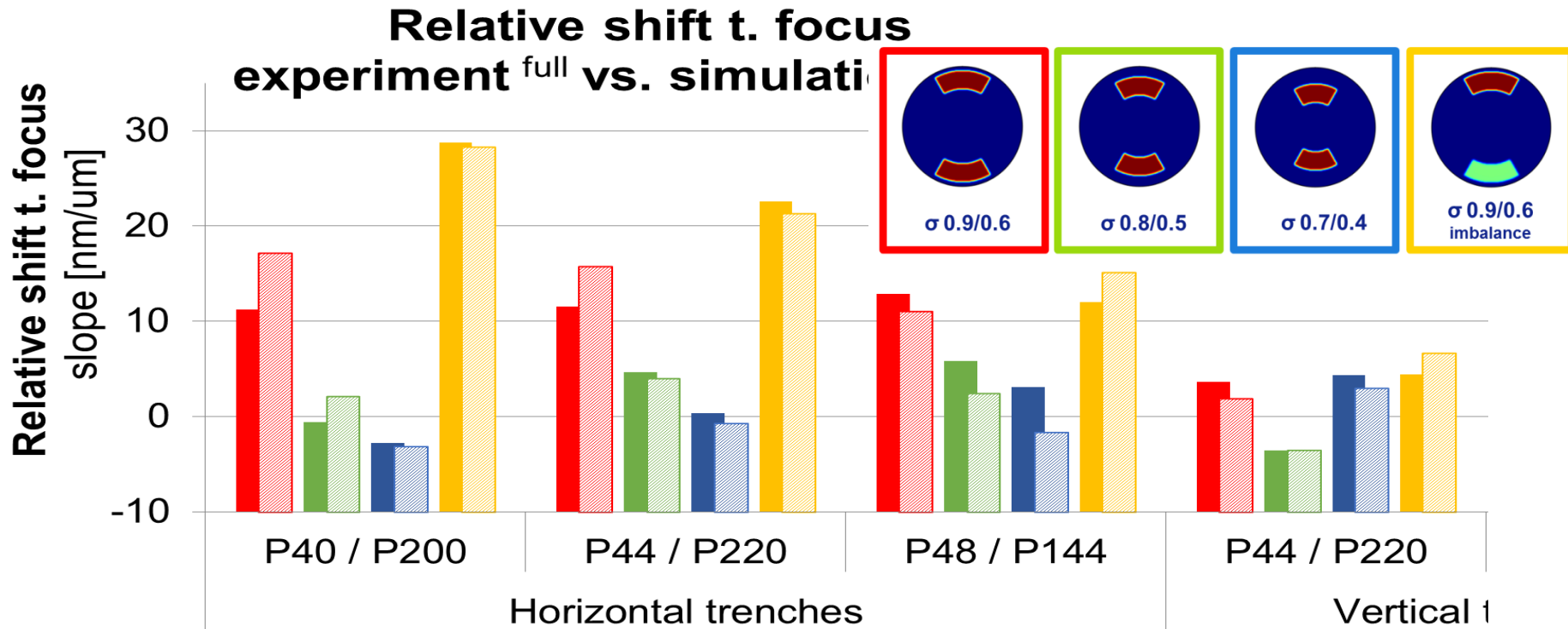
For verification of pattern shift through focus, a method is used that quantifies relative pattern shift through focus based on SEM images of neighboring gratings¹.



¹ V. Philipsen, BACUS 2014

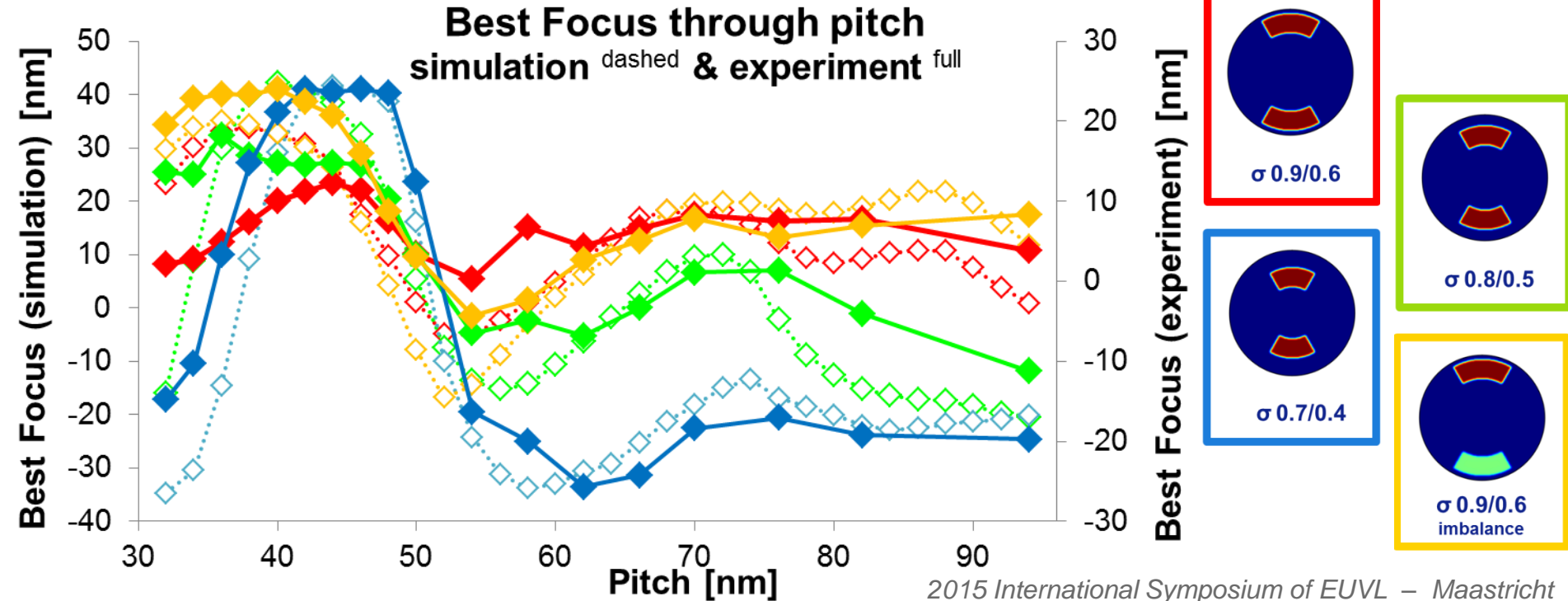
Pattern shift through focus – comparison to simulation

Overall, experimental through pitch and through illumination effects of the relative pattern shift are in agreement with the simulated effects.



Best focus shift though pitch

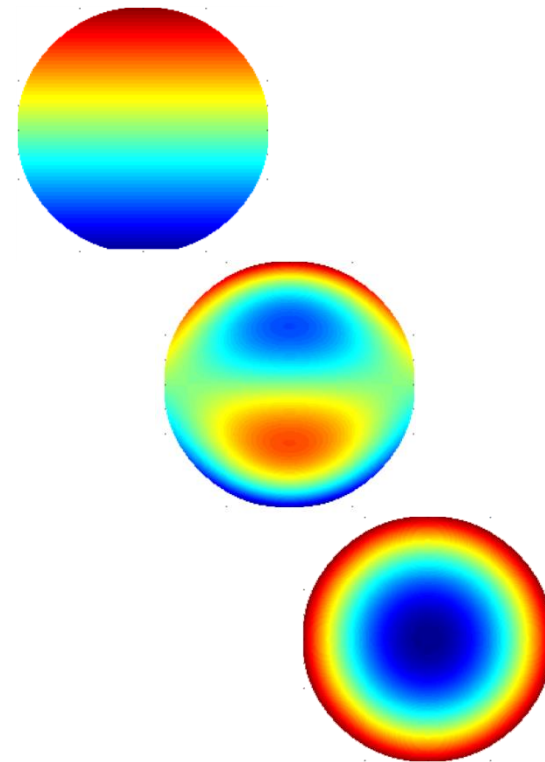
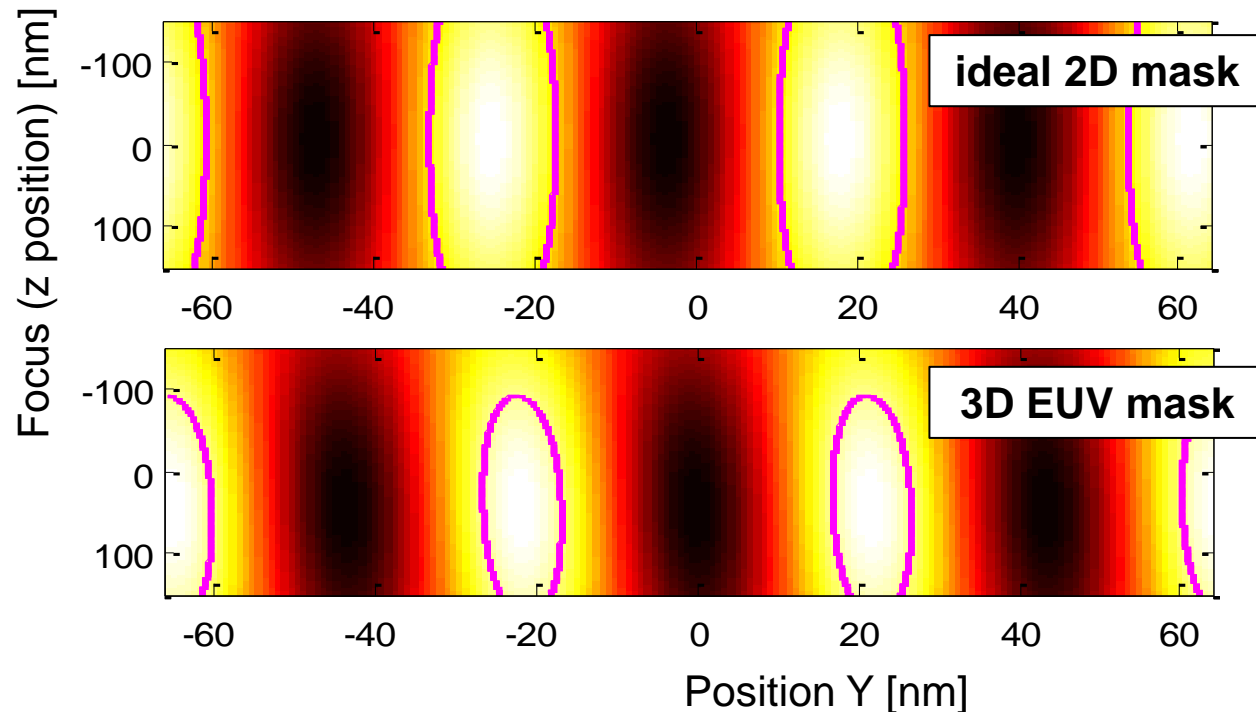
Experimental best focus though pitch trends do match the simulated trends. However, a quantitative agreement is lacking. Experimentally best focus is obtained from a resist pattern quality metric, simulated BF based on NILS.



Aerial Image through focus – 2D vs. 3D mask

Aerial Image through focus

ideal 2D mask and real 3D EUV mask simulation



Aerial images for 22 nm trench 1:1 (pitch 44nm)
dipole Y, 60° $\sigma_{0.7/0,4}$. Intensity scales are not equal.

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Summary & Conclusions

- M3D effects on wafer are explained by phase offsets in the diffracted orders. The effect of pupil variations on best focus shifts and pattern placement through focus is assessed by simulations.
- Relative pattern shift through focus and best focus through pitch curves are experimentally quantified on a NXE:3300 EUV scanner using 4 dipole-Y illumination pupils.
- Simulation predicted relative pattern shift and best focus through pitch are in qualitative agreement with experimental obtained results. Although predicted of best focus ranges overestimate experimental ranges, the trends observed indicate that the illumination pupil can be tuned to reduce M3D effects.



Thank you for you attention!