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Baselining the performance of a EUVL full field scanner through rigorous modeling

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EUVL Full Field Exposure tool

- In August ASML delivered to Albany NanoTech one of the first two EUVL alpha full field scanners.
- To gain an understanding of the imaging capability, the printing of line/space patterns is examined through simulation.
- The simulations include the rigorous modeling of the EUV mask which is assumed to be comprised of a conventional Mo-Si multilayer and a TaN/SiO2 absorber stack.
- The analysis was further constrained to honor the numerical aperture and partial coherence settings of the full field EUVL scanner.

Outline

Simulations of:

- Intrinsic spectral filtering of projection optics box
- Alpha tool imaging including mask, multilayer, and absorber stack
- Aberrations with 3rd order Zernike polynomials

Out-of-band (OOB) Radiation

- EUV Lithography sources produce significant amounts of out-of-band (OOB) radiation.
- OOB radiation in the DUV range will expose* the resist with a low-resolution image of mask pattern (OOB resolution limit ~300-nm).
- OOB exposure is equivalent to short-range flare.

*** Typical EUV resist DUV sensitivity values**

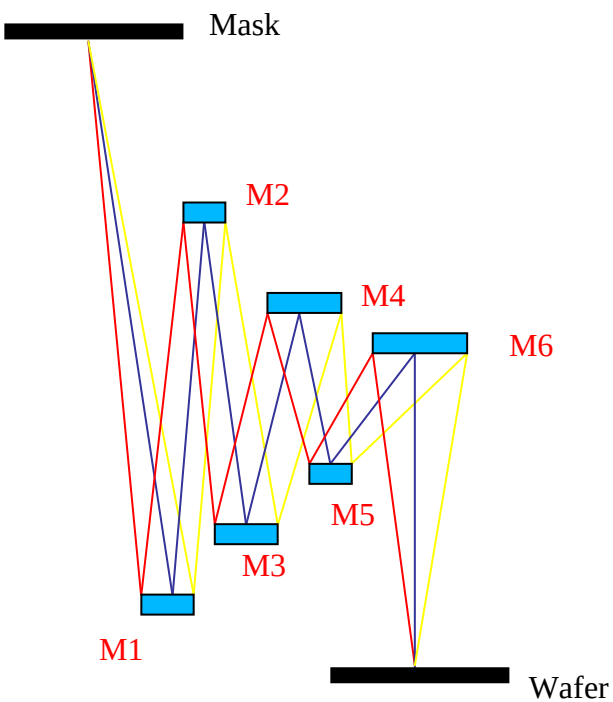
Wavelength (nm)	Relative Sensitivity(mJ/cm^2)
13.5	1
157	0.17
193	2.1
248	0.94

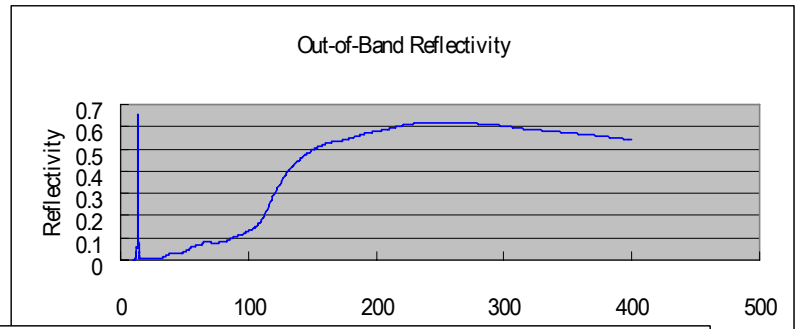
P. Naulleau, Out-of-band sensitivity of typical EUV resist, 2005

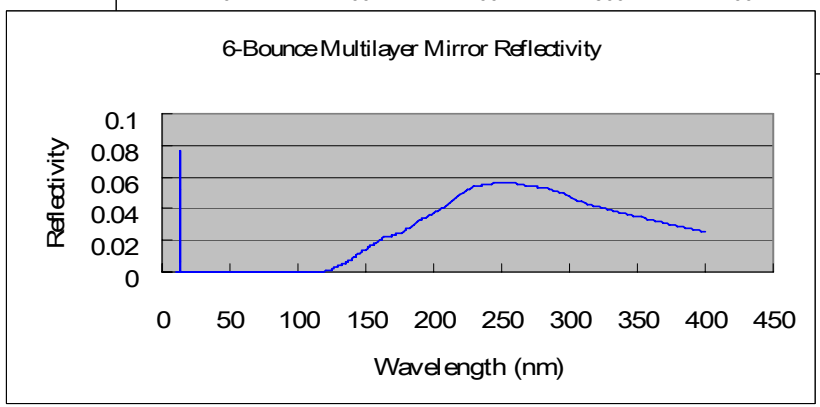
- Sensitivity data has been normalized to the EUV value
- The data showed in the table is based on a single supplier, similar qualitative results have been observed by two other resist suppliers.

Estimation of Total Power at Wafer

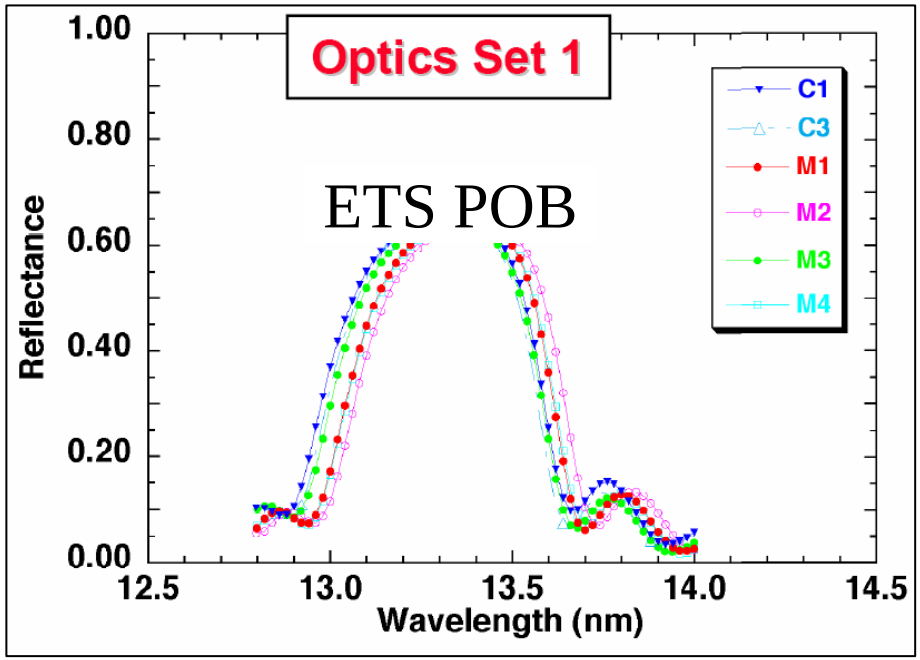
To estimate the in-band power and out-of-band power at the wafer the reflectivity of 6-bounce multilayer mirror system and the input source power were multiplied.

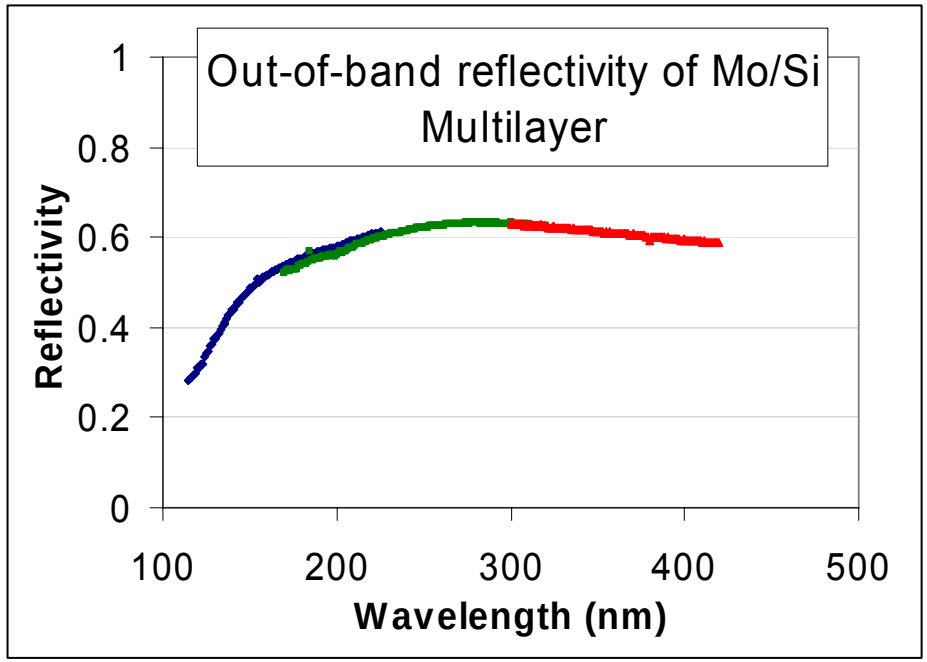






Reflectivity of Representative Multilayer Mirrors



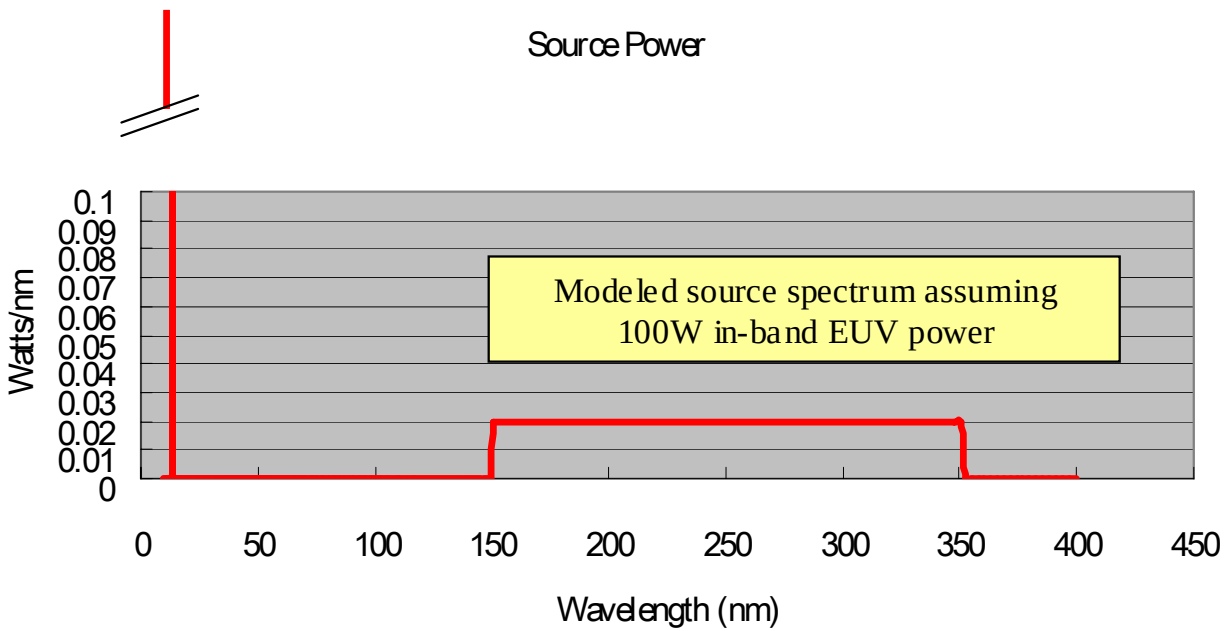


- The four ETS projection optics box (POB) mirrors have reflectivities of 63.8%, 65.2%, 63.8%, and 66.7%, respectively. Average reflectivity is 64.9% (D. Tichenor *et al*, SPIE 4343, p. 19-37, 2001)

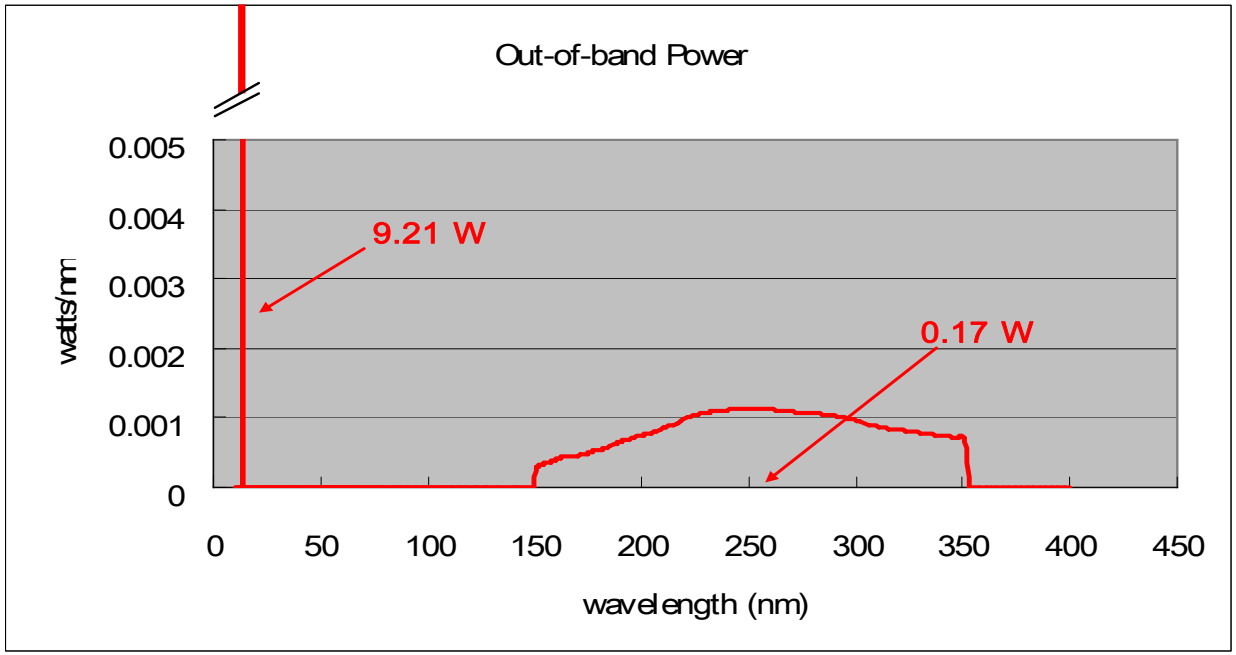
- Peak OOB reflectivity = 63%
- Measurements performed at NIST (M. Chandhok *et al.*, 2004 International EUVL Symposium, Myazaki Japan

Input Source Power

- Based on current estimates for Sn source, 4% OOB radiation expected in the 150 to 350-nm range
- For this estimate OOB radiation is assumed uniform and concentrated in 150 to 350-nm range



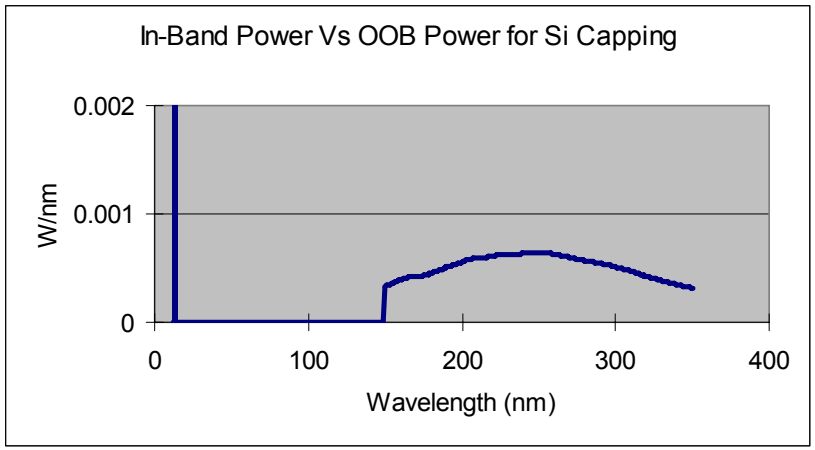
Power Estimation at Wafer



- Assuming 65% EUV reflectivity
- Wafer receives 9.21-W in-band and 0.17-W out-of-band
- 1.9% out-of-band ratio, ~2.1X OOB filtering by POB
- For 63% and 67% EUV reflectivity the OOB filtering would be 1.7X and 2.7X, respectively

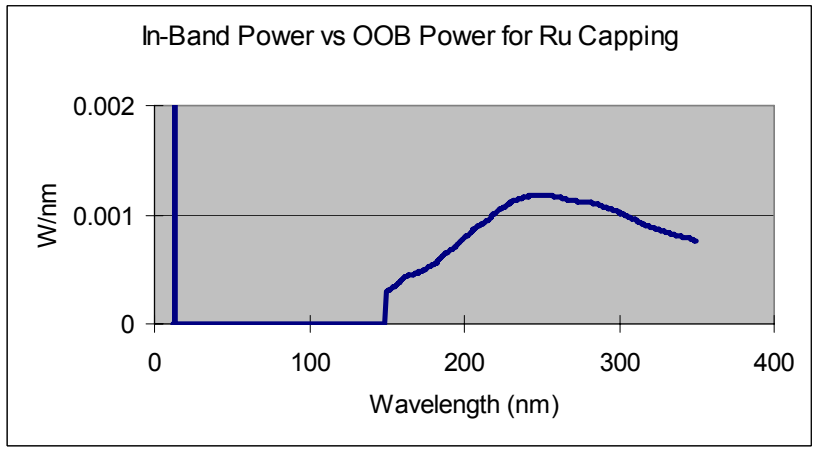
Comparison of Power at Wafer for Si and Ru Capped Reticles

Si Capping Mo/Si ML



- Net OOB power at wafer level = 0.1W for Si capped multilayer

Ru Capping Mo/Si ML



- Net OOB power at wafer level = 0.18W for Ru capped multilayer

- **After 6 bounces OOB power delivered to wafer of Ru capped multilayer is 1.8X larger than Si capped multilayer**

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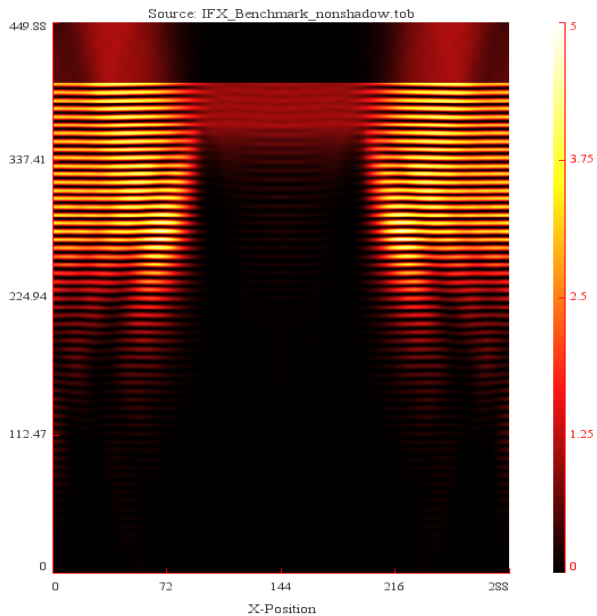
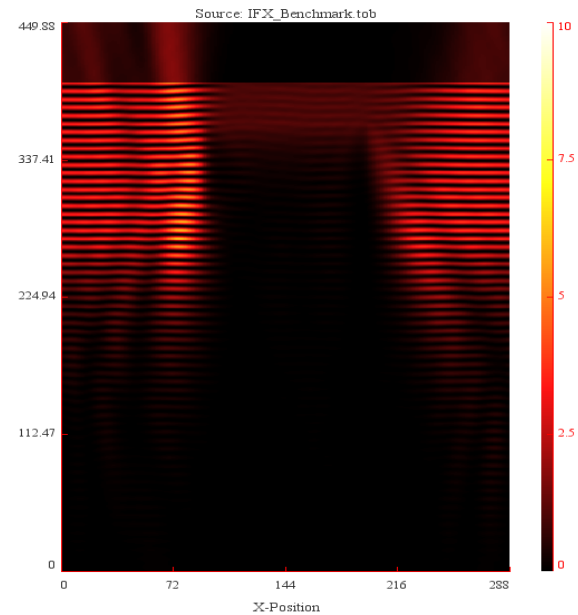
Non-shadowed and shadowed imaging

As EUVL illuminates the mask at a 6°angle of incidence first pass analysis was centered on the imaging of shadowed (off-axis illumination) line space features and the induced image placement error, IPE.



On-axis illumination (non-shadowed) near field intensity plot



Off-axis illumination (shadowed) near field intensity plot

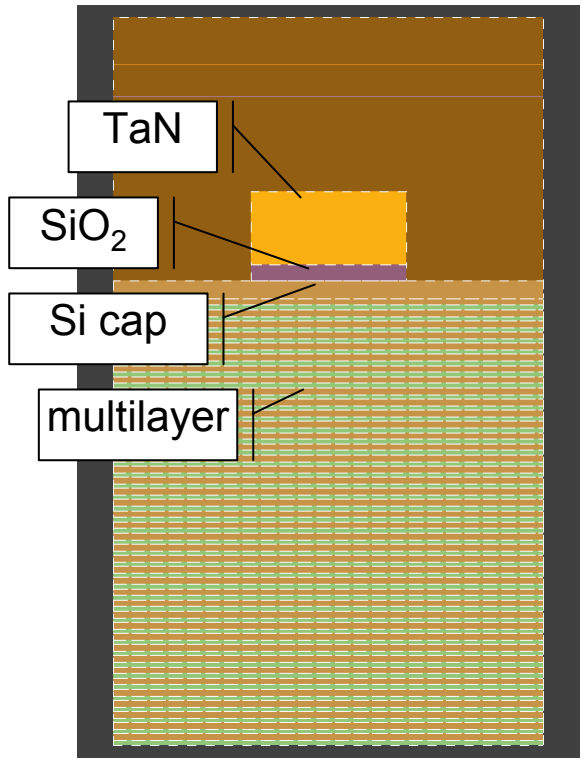
Parameters: Fixed Pitch Modeling Through CD and Defocus

Modeled dense L/S pattern at a fixed pitch of 72nm

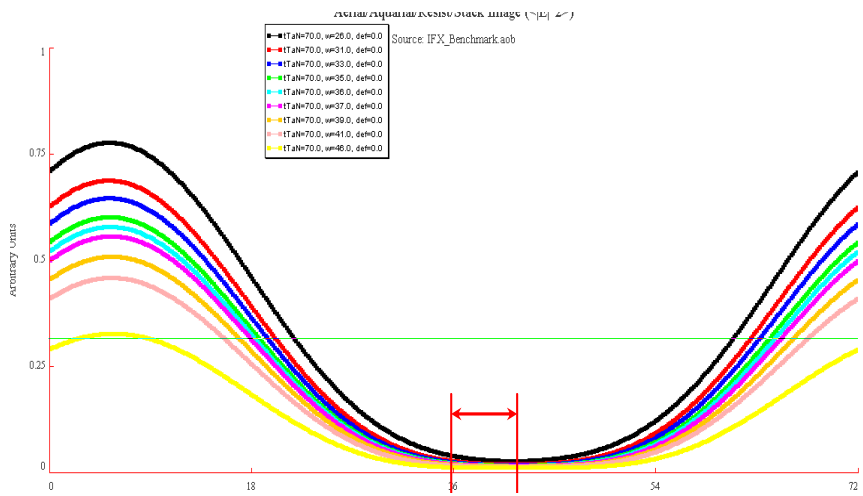
- Line-widths: 26nm through 46nm
- Optic-settings: NA = 0.25, sigma = 0.5, Angle of incident = 6°, Magnification = 4x,
- Wavelength = 13.4nm, No flare, No aberrations
- x-resolution: 1 nm

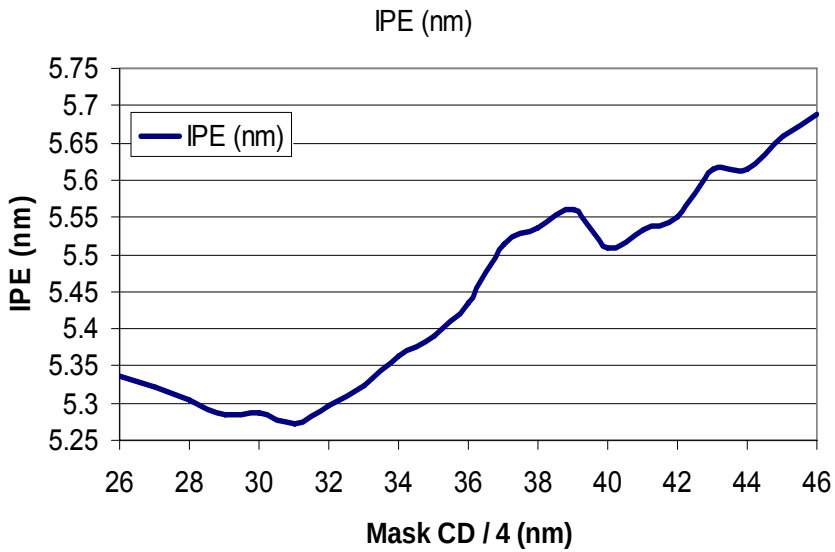
Mask Stack Properties (@λ= 13.4nm):

- Substrate:
  - Si:: n = 0.99931, k = -0.00182109
- Mo/Si Multi-layer – 40 times:
  - Mo:: n = 0.922737, k = -0.0062202, thickness = 2.76nm
  - Si:: n = 0.99931, k = -0.00182109, thickness = 4.14nm
- Capping layer:
  - Si:: n = 0.99931, k = -0.00182109, thickness = 11.0nm
- Absorber stack:
  - SiO_2 Buffer:: n = 0.97871, k = -0.0105698, thickness = 10nm
  - TaN Absorber:: n = 0.925191, k = -0.0441162, thickness = 70nm



Pattern Shift Through CD Range



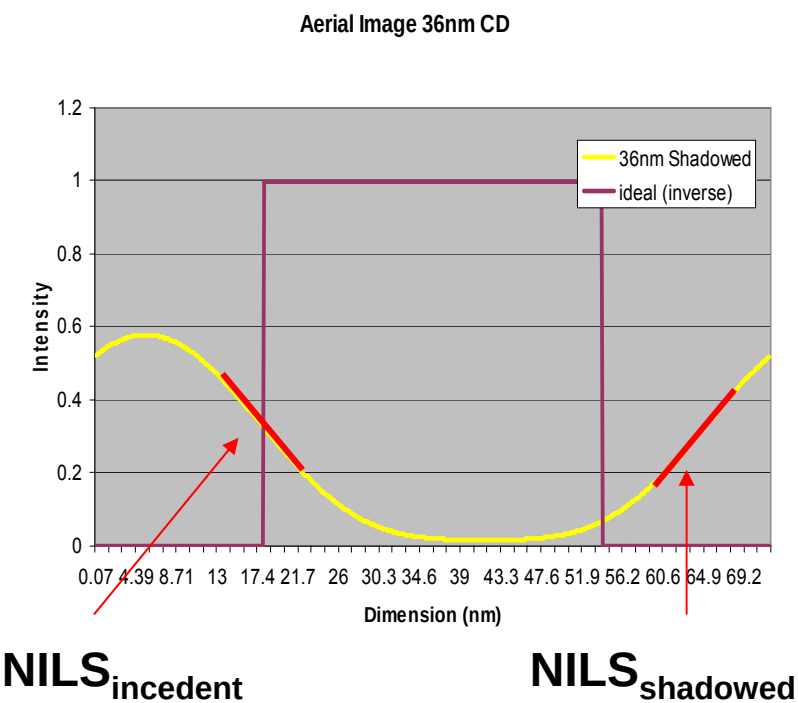


- Pattern displacement of the shadowed reticle feature was calculated using the delta of center point of the reticle image to the center point of the aerial image.

- **The results show, that for a fixed pitch, there is a dependence of the image placement error, IPE, to linewidth.**

Asymmetry Factor (κ)

Image placement error for varying absorber film thicknesses has been previously reported by Minoru Sugawara *(Minoru Sugawara et al, The Japan Society of Applied Physics, Vol. 44, p. 8409-8421, 2005)* where he defined the asymmetry factor, a measure of the contrast difference of the shadowed and non-shadowed edges of an aerial image



$$\kappa = \left(\frac{\left| NILS_{incidencce} \right| - \left| NILS_{shadow} \right|}{\left| NILS_{incidencce} \right| + \left| NILS_{shadow} \right|} \right) \times 100(\%)$$

where: $$NILS = w \frac{d \ln I(x)}{dx}$$ (*w* is the wafer level target CD)

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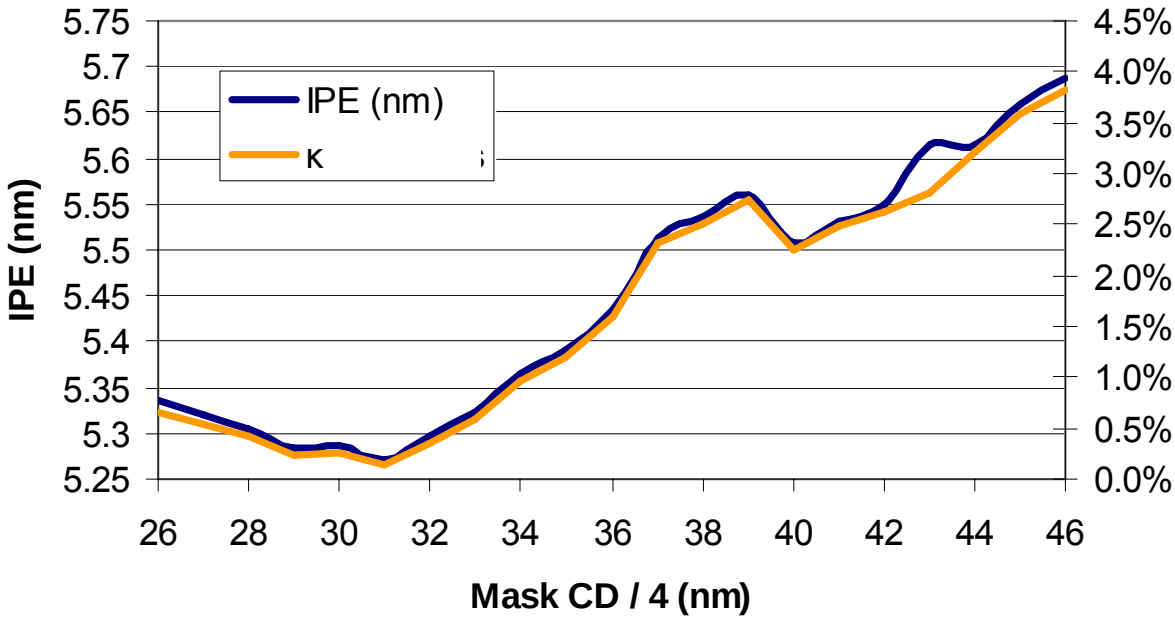
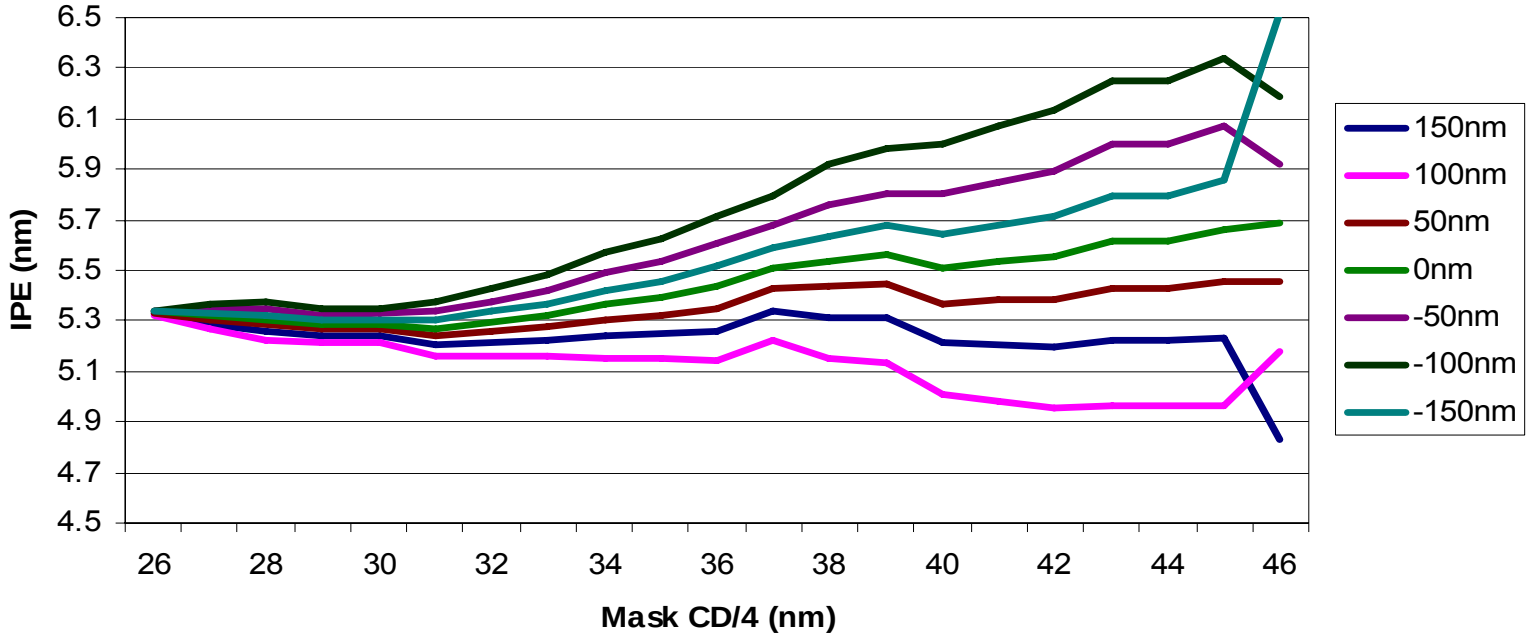
IPE and Asymmetry Factor (κ)



- There is a strong correlation between the asymmetry factor and pattern placement.
- This indicates that the IPE is dependant on the contrast of the pattern edges.
- As the NILS varies as a function of focus, the IPE of a feature illuminated off-axis should also vary through focus

IPE through Defocus



- The IPE through focus shows a dependence.
- As pattern density is reduced (smaller linewidth, larger space) the variation becomes smaller.
- This effect needs to be quantified over a wider range of features and conditions

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3rd Order Aberration Effects

- The impact of a aberrated alpha tool lens on the imaging of 40nm, 45nm and 50nm dense lines and space features has also been simulated.
  - As the lens data was not available the total wavefront error of the tool specification was applied separately to the Zernike coefficients
    - Astig 0/90, Astig 45/135, Coma X, Coma Y and spherical aberration effects were simulated.
    - Both shadowed and non-shadowed features were evaluated using the same mask film stack as in the IPE analysis
  - For lens aberrations at the tool specification level Coma X and Spherical demonstrated a weak response to the aberrations.
- For the targeted resolution of the alpha tool there should not be any significant imaging effects due to these lens aberrations

Summary

- Analyzed intrinsic spectral filtering of projection optics box
  - Spectral filtering by POB itself is minimally efficient, reduces relative out-of-band power by a factor of ~2
  - Ru capped multilayers are less effective in filtering OOB radiation then those that are Si capped
  - Additional spectral filtering may be required if any significant amount of OOB radiation is delivered through source and illuminator
- Aerial image modeling of the alpha tool including mask, multilayer, and absorber stack
  - For a fixed pitch the image placement error, IPE, varies relative to linewidth
  - There is a good correlation of IPE to asymmetry of the edge contrast of the reticle features illuminated off-axis
  - Pattern displacement modeling shows that IPE has a focus dependence.
  - More work needed to quantify the significance of this dependence
- Aberrations effects modeling with Zernike polynomial coefficients
  - For POB meeting the wavefront specification, there should be minimal influence of aberrations to imaging of 40nm, 45nm and 50nm dense line/space features