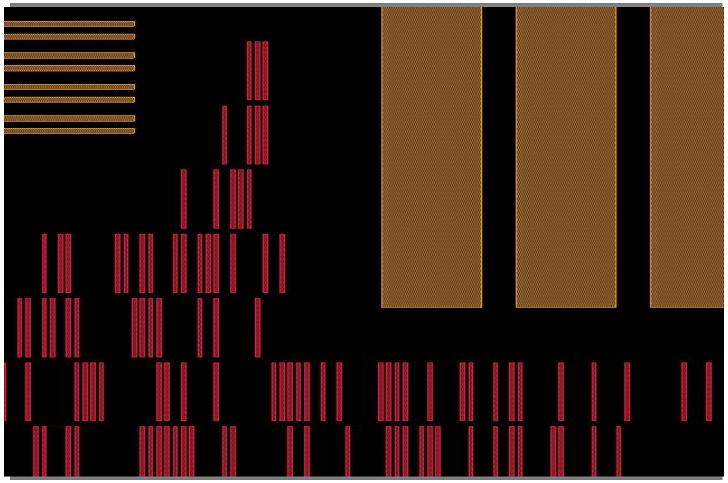
Flare compensation in EUV lithography



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Outline

- Description of EUV flare
- Calculation details
- Compensation strategies
- Conclusions

Flare in EUV lithography

- Cause: surface roughness on optics
- Scales as $1/\lambda^2$, so more problematic at EUV wavelengths
- Effects:
  - Scatters light out of bright regions and into dark regions $\Rightarrow$ reduces contrast
  - Couples local light intensity to features 1000's of mm away $\Rightarrow$ pattern dependent
- Simple calculations $\Rightarrow$ 1% (absolute) change in flare causes 0.86 nm CD change

Estimating impact of flare variation on CD control

- Statistical simulation parameters (CCI design)
  - **Average mask transmission: 80–90%**
  - **Mean focus error: -0.05–0.05 μm**
  - **Cross-slit focus variation (1σ): 0.006–0.008 μm**
  - **Mean dose error: ±10%**
  - **Cross-slit dose variation (1σ): 2.0–2.6%**
  - **Mean flare: 10–15%**
  - **Flare variation (1σ): 1–3% (absolute)**
  - **500 calculations per set of conditions**
- Constant simulation parameters
  - **45nm lines on a 110nm pitch**
  - **Partial coherence = 0.7**
  - **NA = 0.25**
  - **Wavefront error = 0.045λ**
  - **Absorber stack 120nm thick**
  - **Normal incidence**

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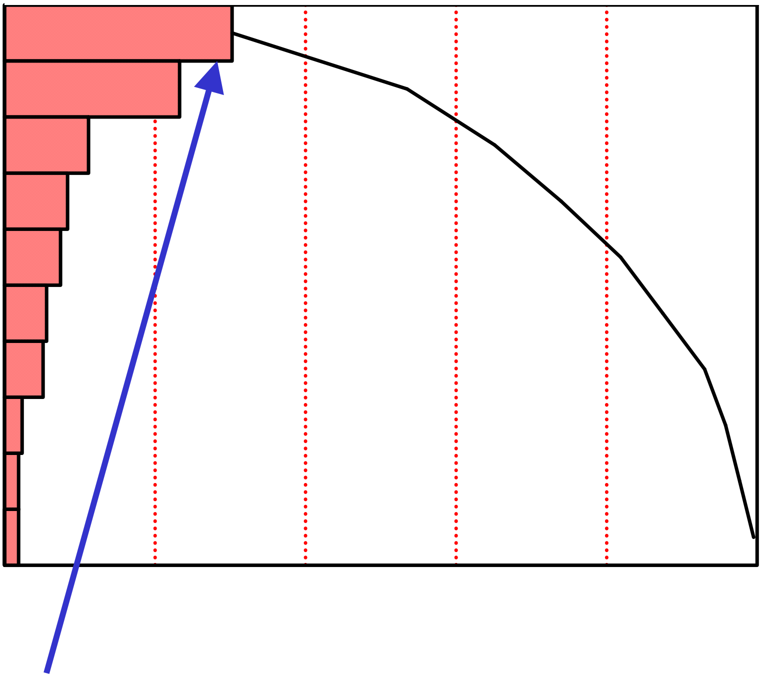
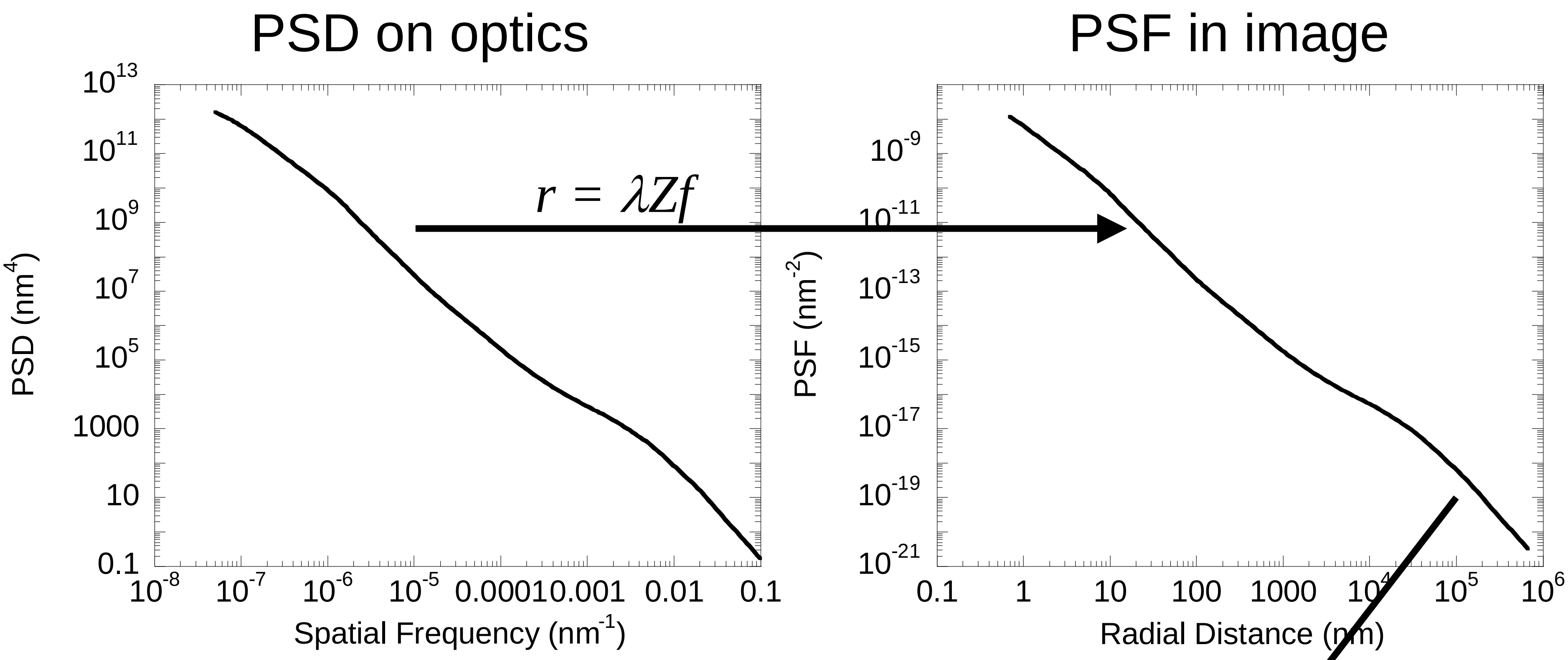
Simulation results

Term	Orthog Estimate
Flare_Var(1,3)	-0.0424507
Def_Err(-0.05,0.05)	0.03301723
Dose_Mean(0.27,0.33)	0.01629922
Flare_Mean(10,15)	-0.0122251
Mask_T(80,90)	-0.0108554
Def_Err(-0.05,0.05)*Flare_Var(1,3)	-0.0083664
Def_Var(0.02,0.03)	-0.0074315
Mask_T(80,90)*Flare_Mean(10,15)	-0.0037086
Def_Var(0.02,0.03)*Dose_Mean(0.27,0.33)	-0.0029393
Mask_T(80,90)*Dose_Mean(0.27,0.33)	-0.0029023



- Flare variation is largest factor influencing CD control
- Effect of flare variation is 3.5X the effect of mean flare
- Model predicts 1σ flare variation must be less than 1.7% (absolute) for ±10% CD control at -0.05 μm focus error

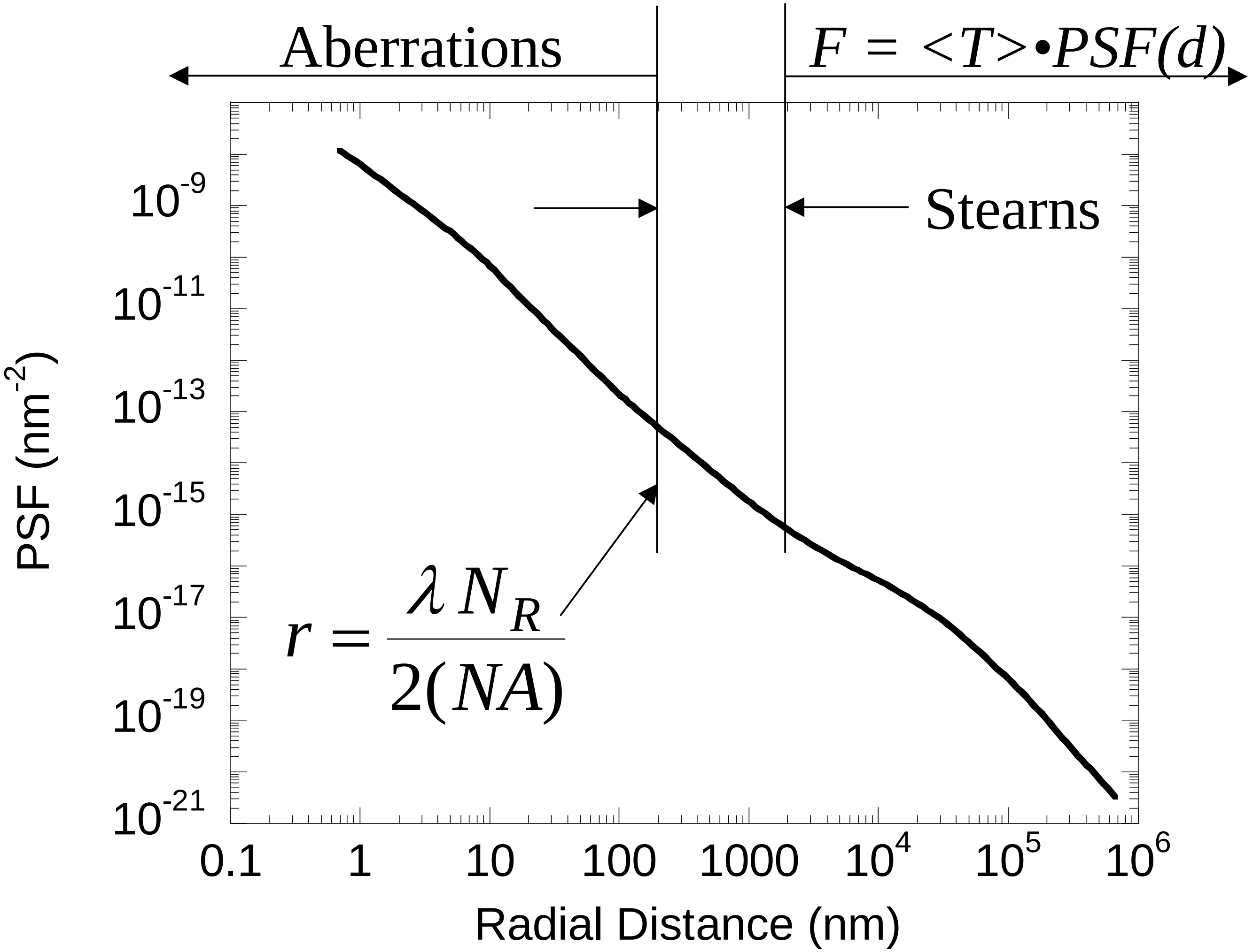
Flare calculations, p. 1

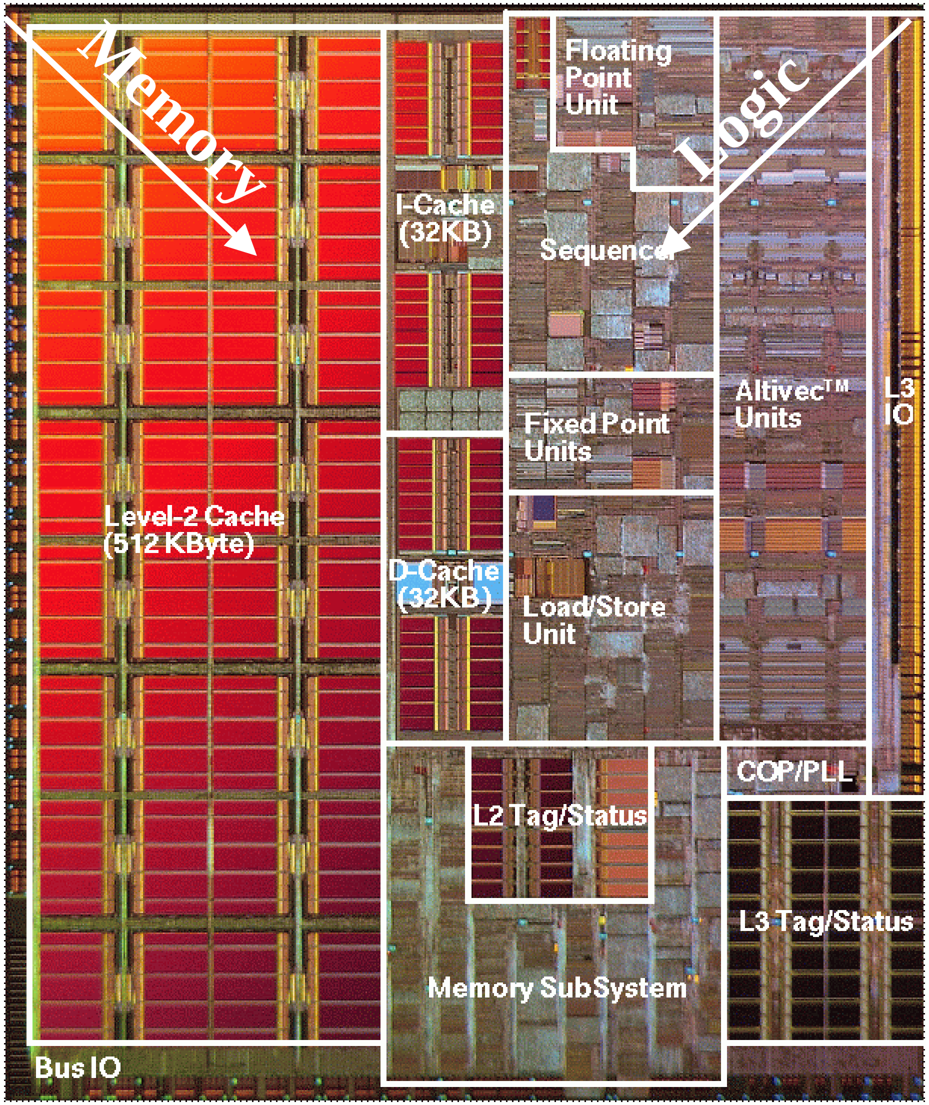


Stearns *et al.* (*J. Appl. Phys.* **84**, 1998):

$$I(x,y) \propto I_0(x,y) + I_0(x,y) \otimes PSF(x,y)$$

Flare calculations, p. 2





Flare calculations

- Data scaled so that poly lines are 0.09 µm (appropriate for 0.1 NA ETS)
- Include measured aberrations from ETS field center
- Average flare over 0.09x0.09 μm^2 regions inside of a 2x2 mm^2 section of mask data

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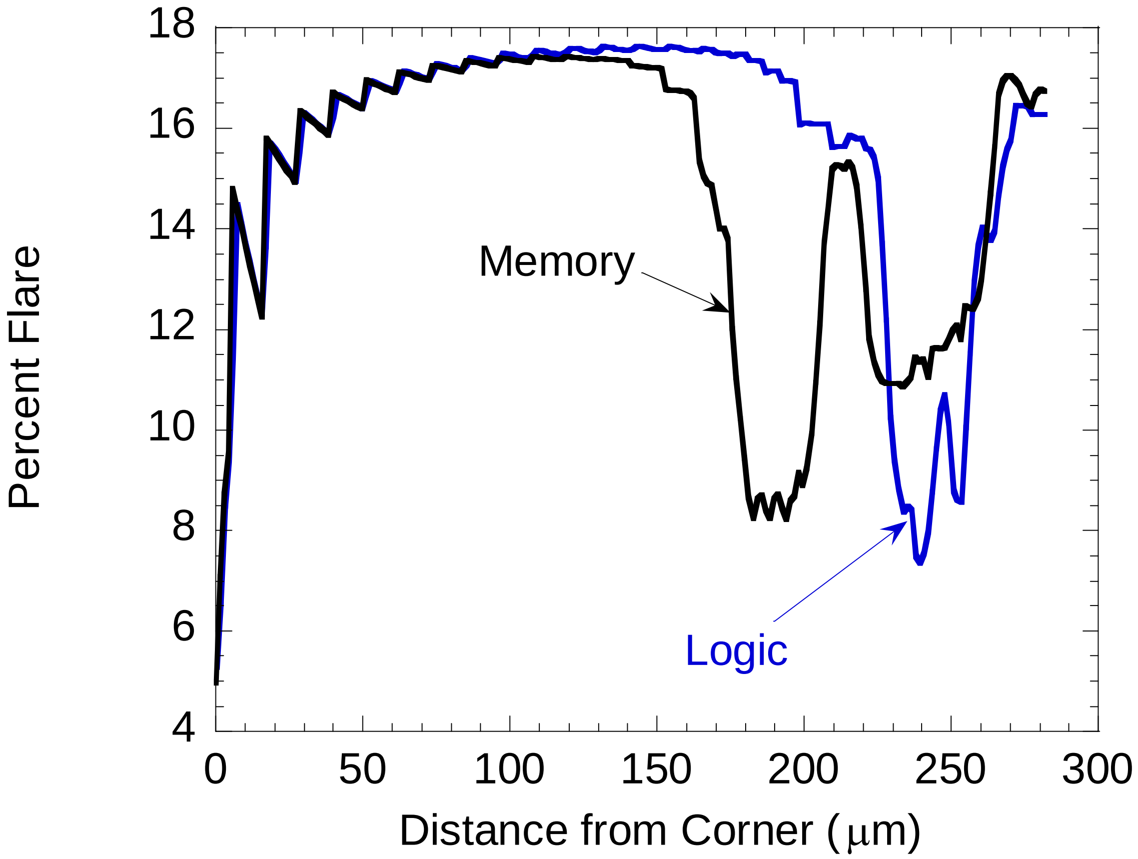
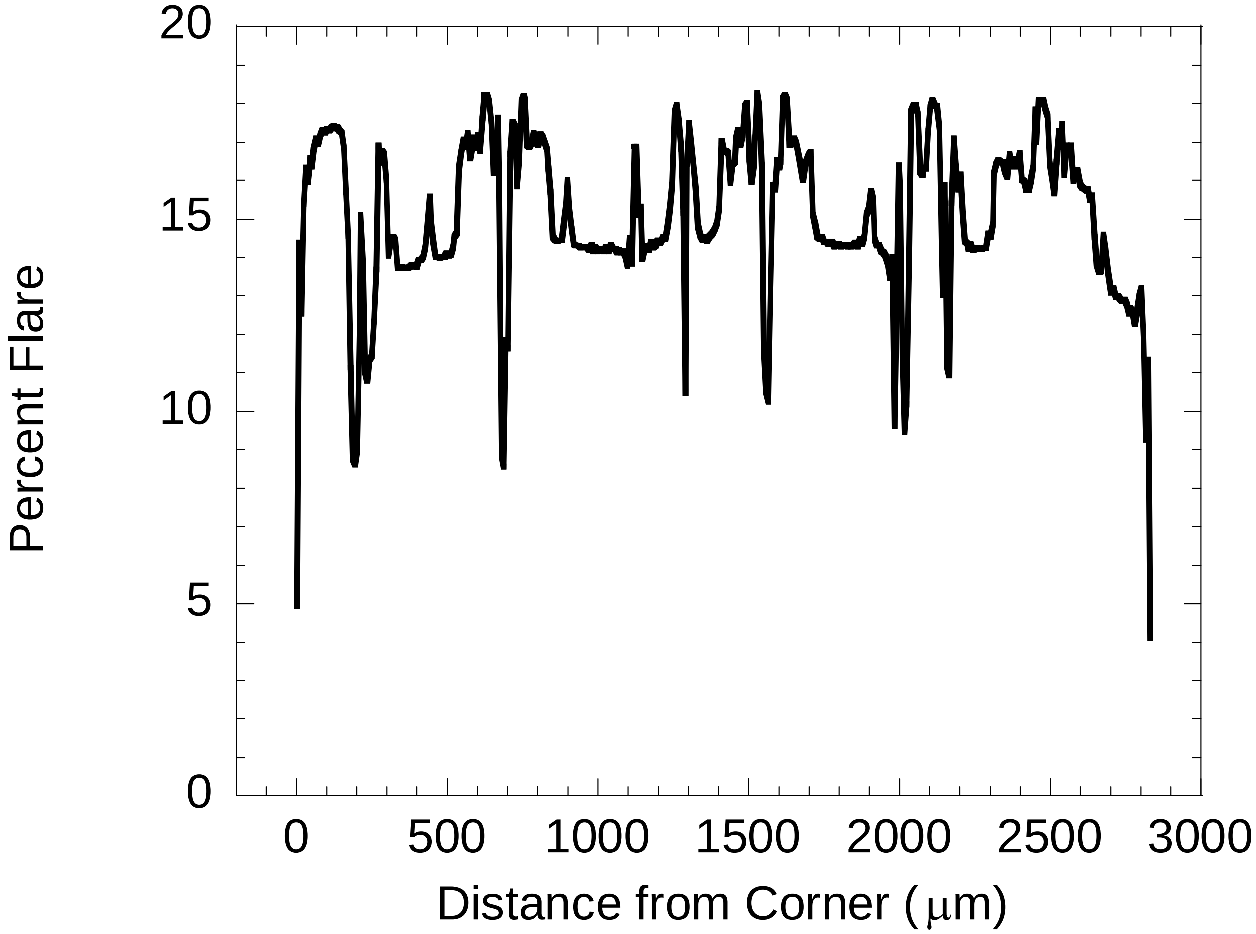
Calculation results



Proposed compensation strategies (Krautschik *et al.*)

- Selective sizing
  - **Resize lines according to known d(CD)/dF response**
  - **Apply global resizing in middle of mask where flare variation assumed to be small**
  - **Apply local resizing in corners where variation is largest**
  - **Iterate to convergent solution**
- Dummification (i.e., tiling)
  - **Reduce flare variation by reducing pattern density variation**
  - **Add dummy features to areas of low pattern density**
  - **Dummy features must not interfere with circuit function**

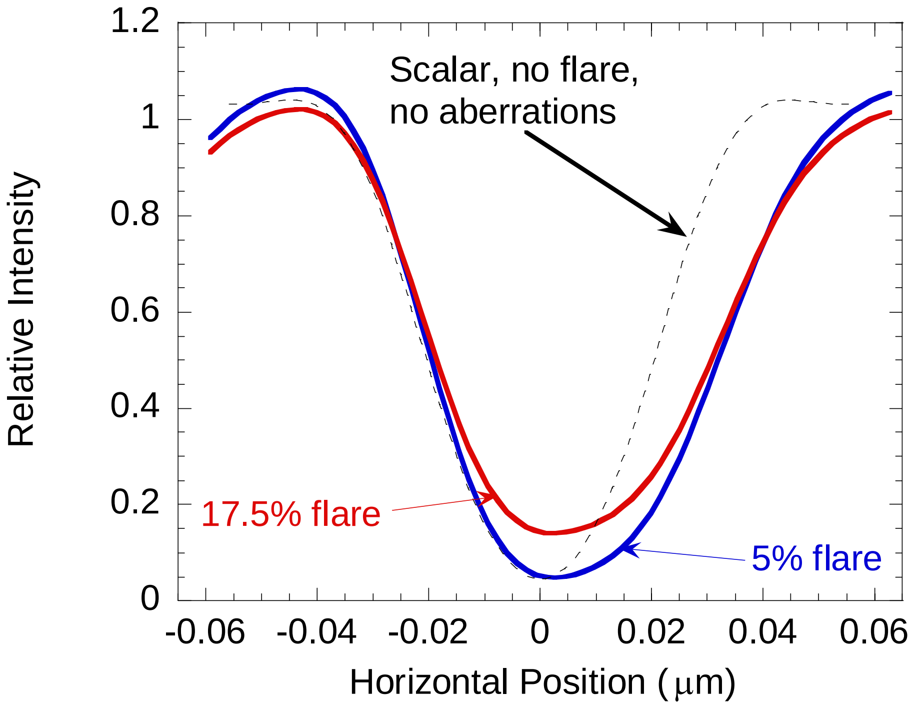
No place to apply global resizing

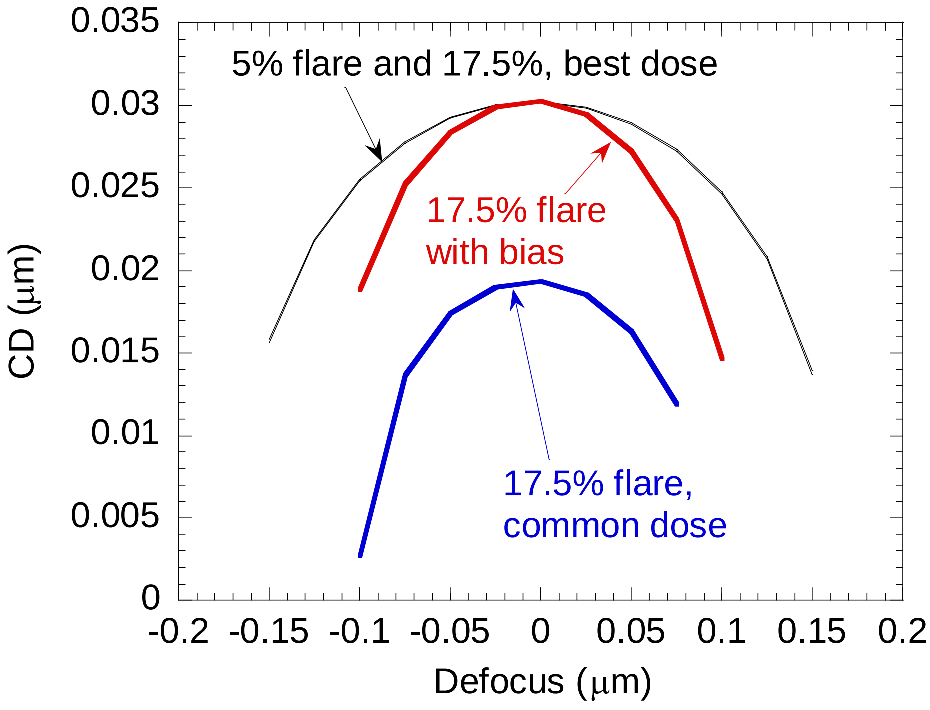


Effects of sizing on process window

$$I(x,y) = I_0(x,y) \times (1-F) + F \times \langle T \rangle$$

$$\mathrm{NA} = 0.25,\ \Theta_i = 6°,\ \sigma = 0.7,\ \lambda = 13.5\ \mathrm{nm},\ \langle T \rangle = 75\%$$





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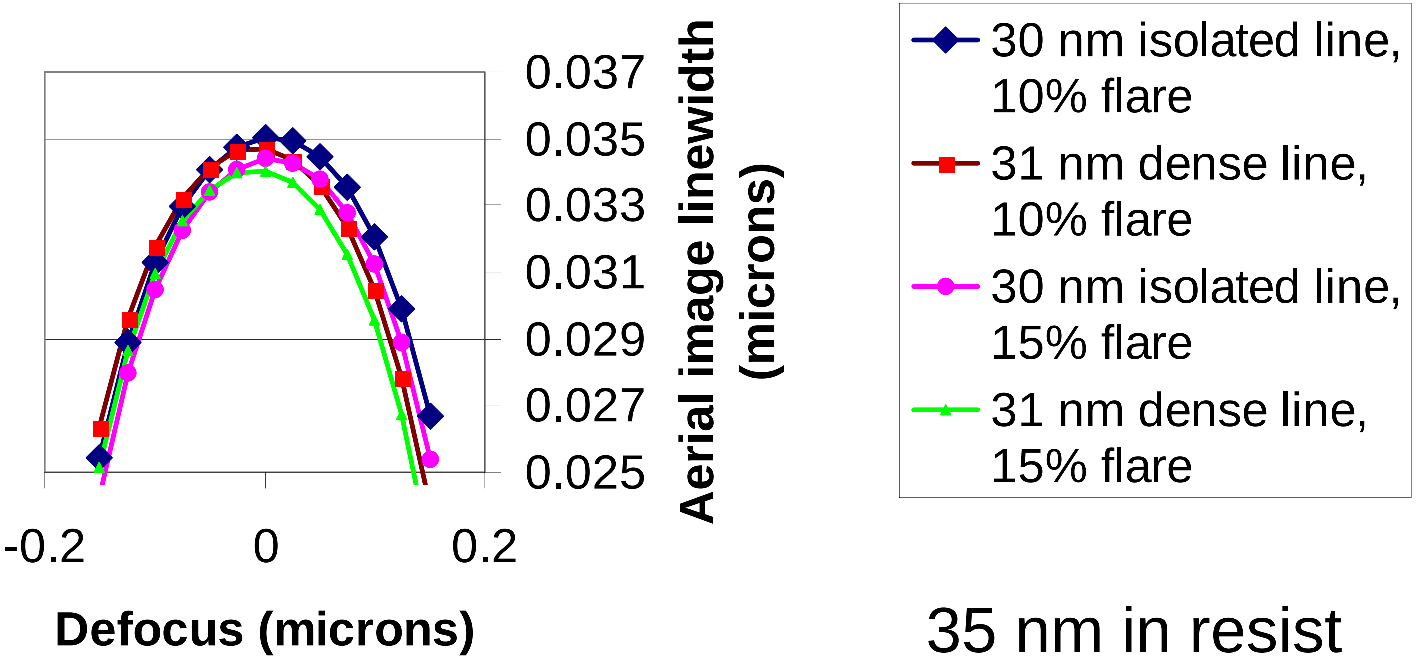
Overlapping process window for dense and isolated lines possible with biasing but smaller window than without flare variation



35 nm in resist
Dense: 90 nm pitch
Isolated: 270 nm pitch

25% average pattern density

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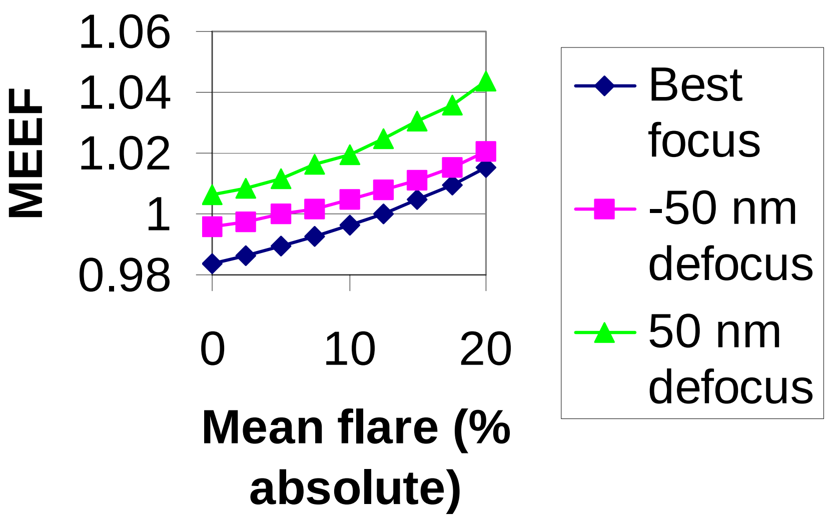
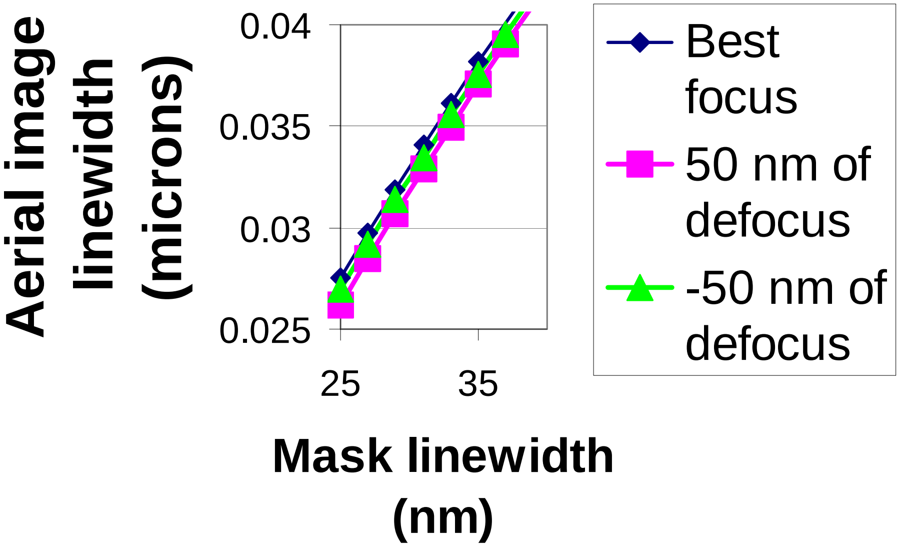
MEEF effects minimal, and mean-to-target CD control not critical for biasing





- MEEF varies with flare and focus
  - **Effect of focus larger but only 1-2%**

- Linear behavior implies MTT CD control not critical

35 nm in resist; 90 nm pitch

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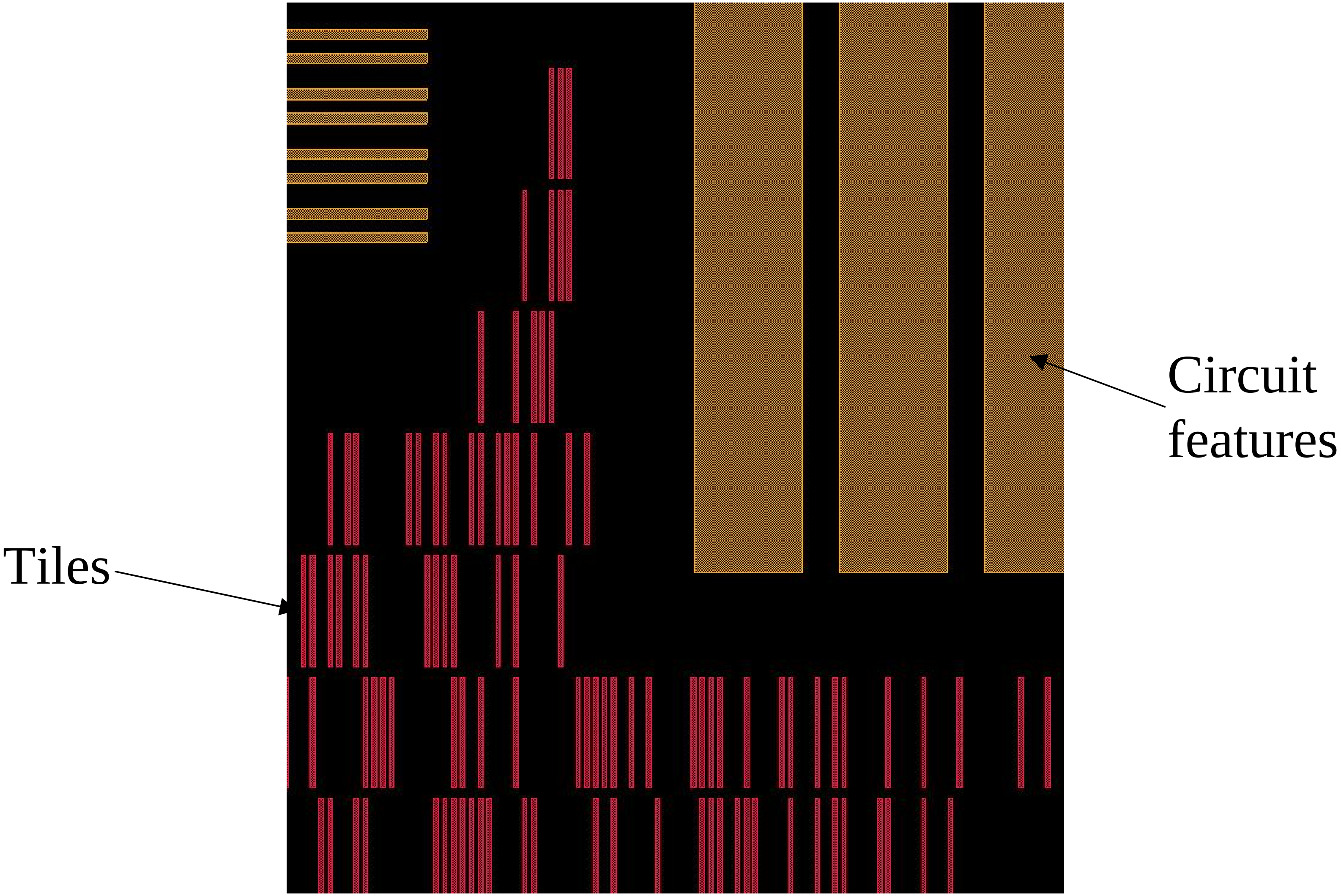
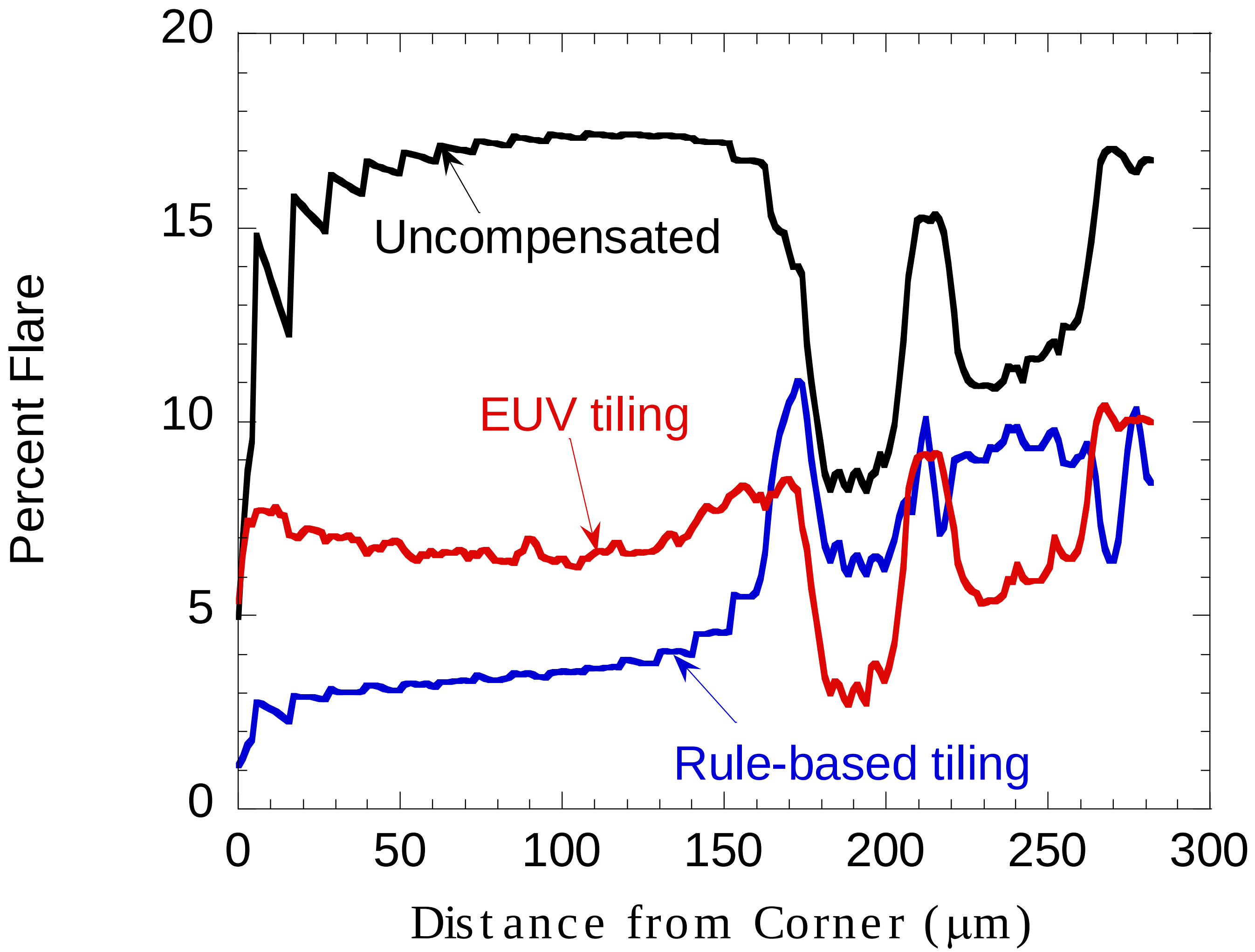
Various tiling algorithms tried

- Origins in CMP processes
- Rule-based
  - **Insert dummy features in all appropriate empty space**
  - **Increases pattern density uniformity over short length scales**
- Model-based CMP
  - **Insert tiles according to empirical model that relates pattern density and polish uniformity**
  - **Considers weighted pattern densities over mm length scales**
- Model-based EUV
  - **Place subresolution tiles**
  - **Minimize pattern density variation with optimization calculation that attempts to consider all relevant length scales in PSF**
  - **Extend tile placement into borders with model-based CMP algorithm**

Tiles from EUV algorithm



Effects of tiles on flare



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Conclusions

- Barring significant improvements in EUV optical fabrication technology, mask compensation will be required to reduce flare variation
- Selective sizing is feasible but is computationally expensive and reduces the focus latitude
- Tiling also reduces variation but certain features are not tiling-friendly
- Both selective sizing and tiling will likely be required for full compensation