Lawrence Berkeley National Laboratory

Optics, mask and resist implications on contact CDU

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Special thanks to Gregg Gallatin

Outline

Condenser flare

Mask CDU

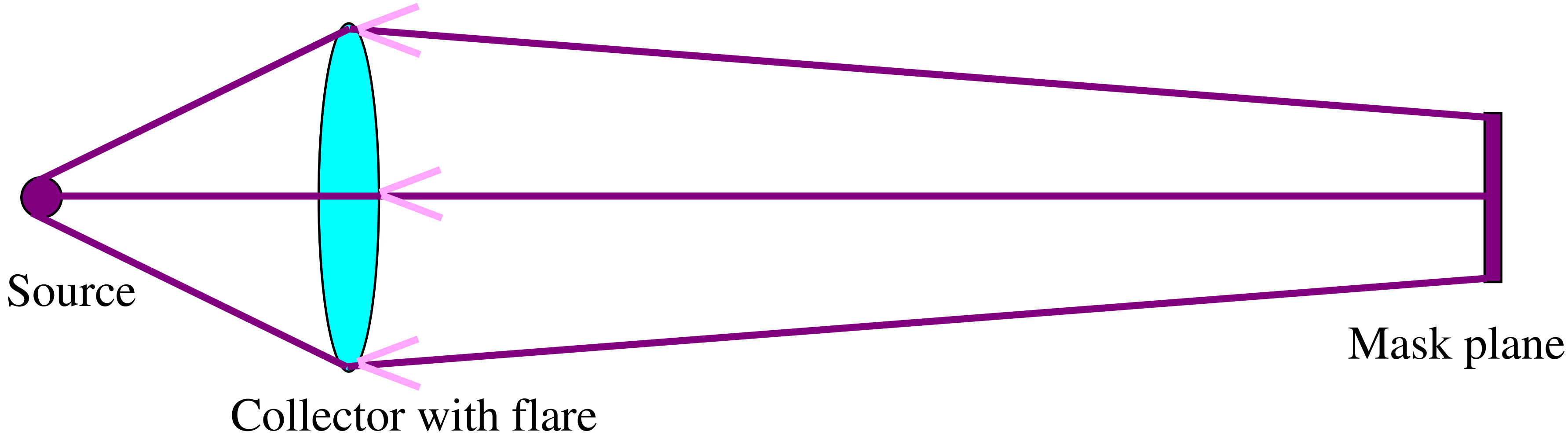
Mask roughness

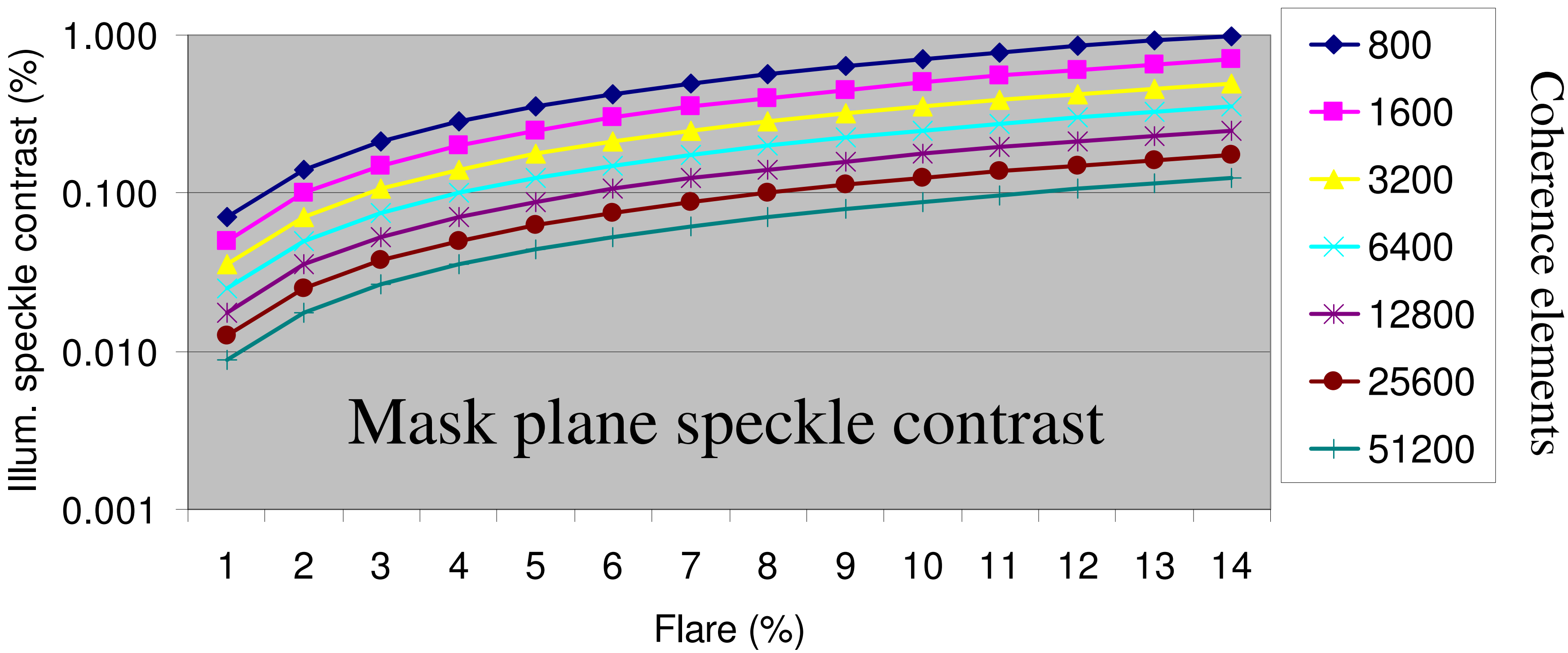
Shot noise

Resist blur

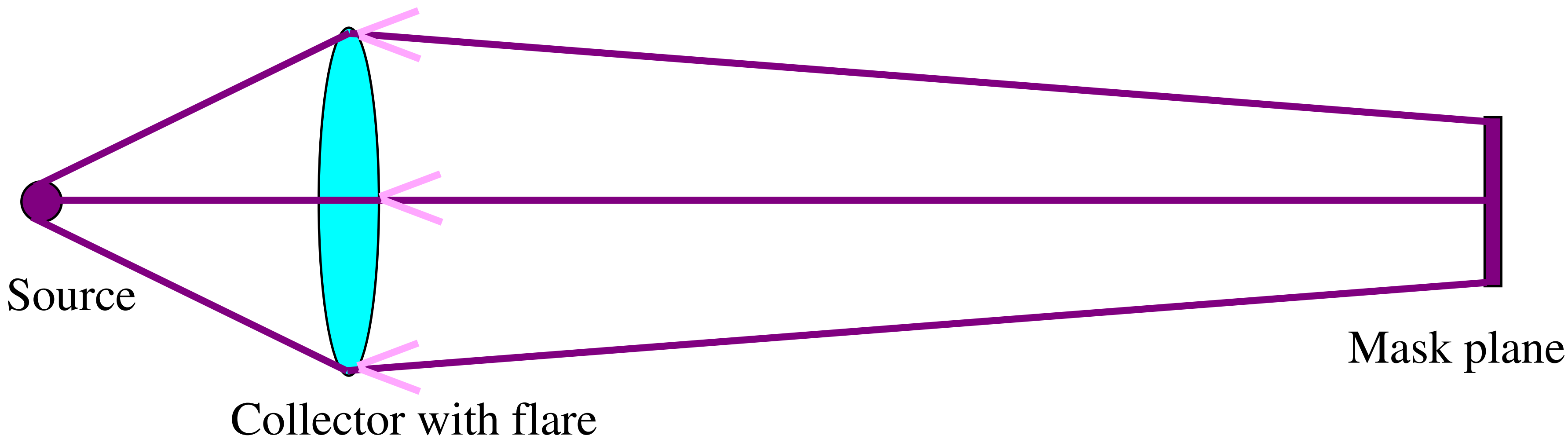
Summary

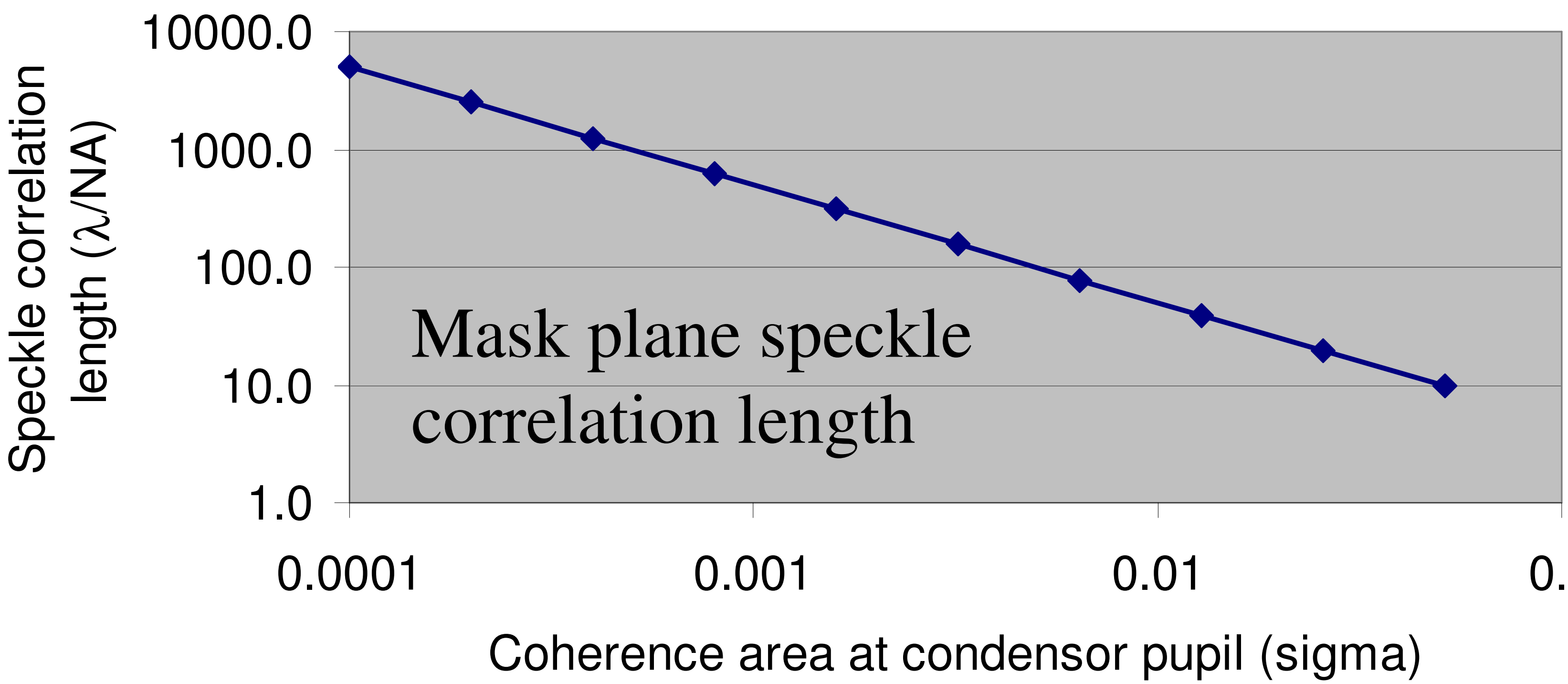
Source collector roughness





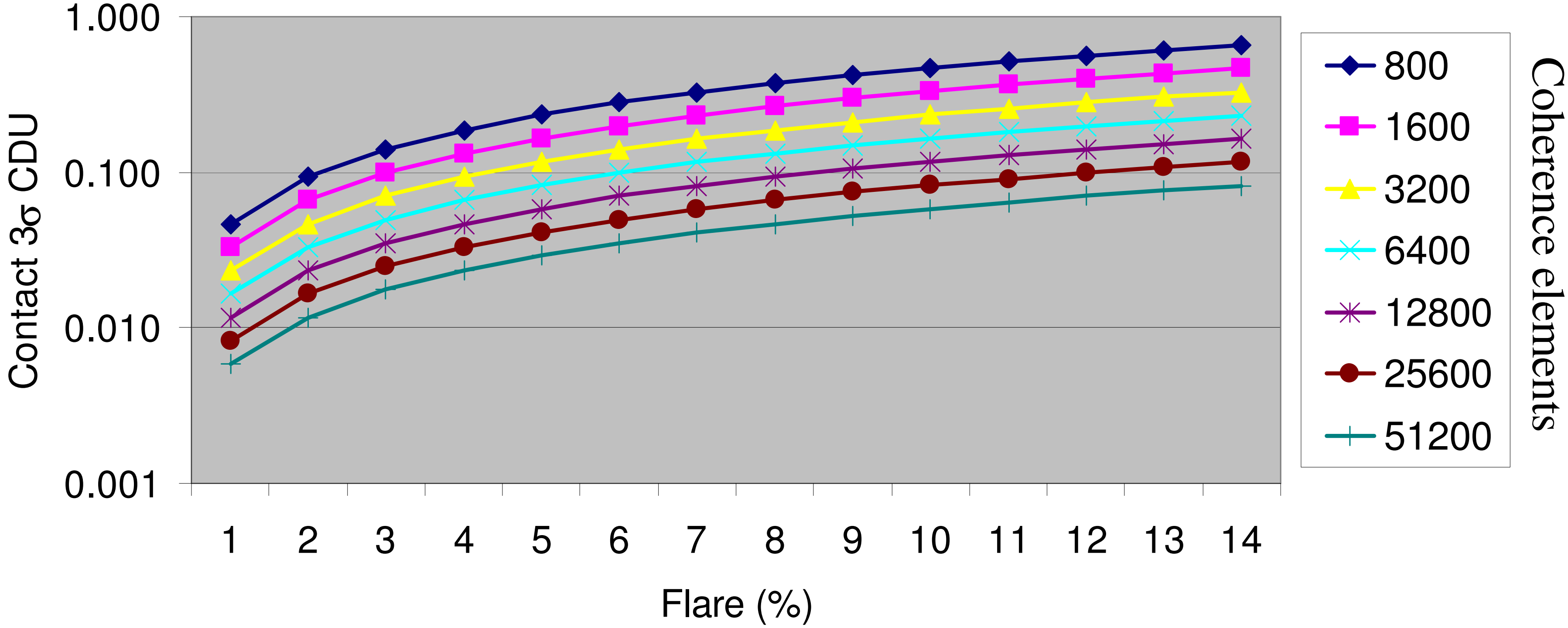
Source collector roughness



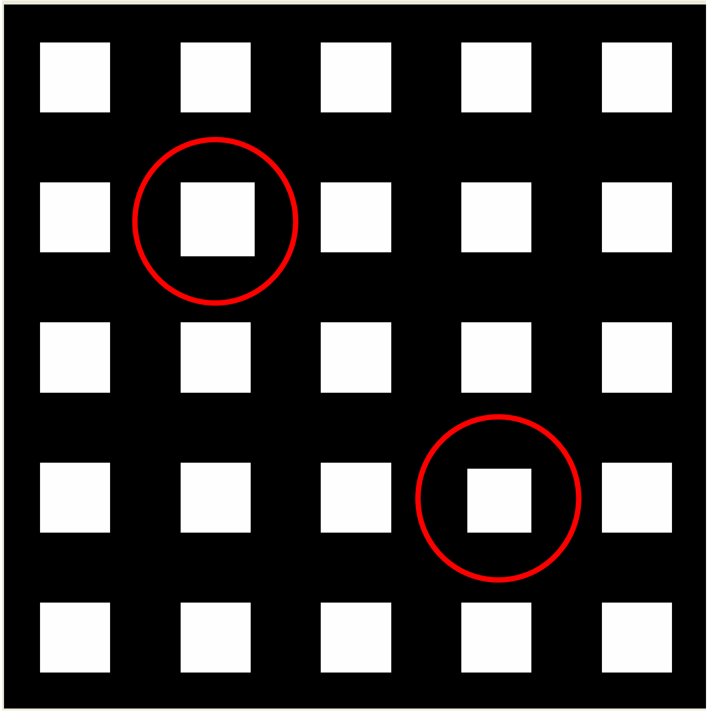


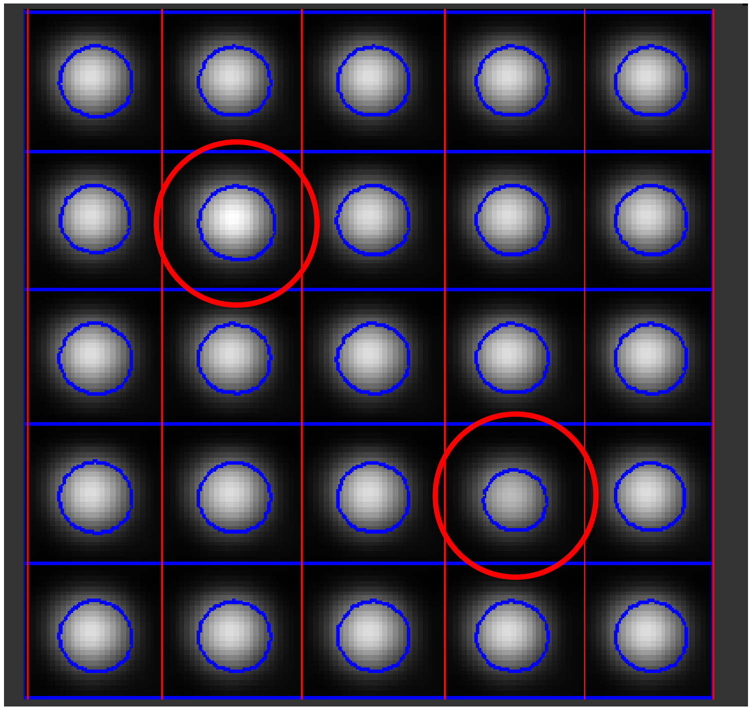
Source collector roughness coupling to contact CDU

NA = 0.32, quadrupole illumination, 28-nm dense contacts



Mask CDU





NA = 0.32, disk 0.7, 28-nm dense contacts
MEEF = 1.5
Results independent of aberrations up to 1 nm

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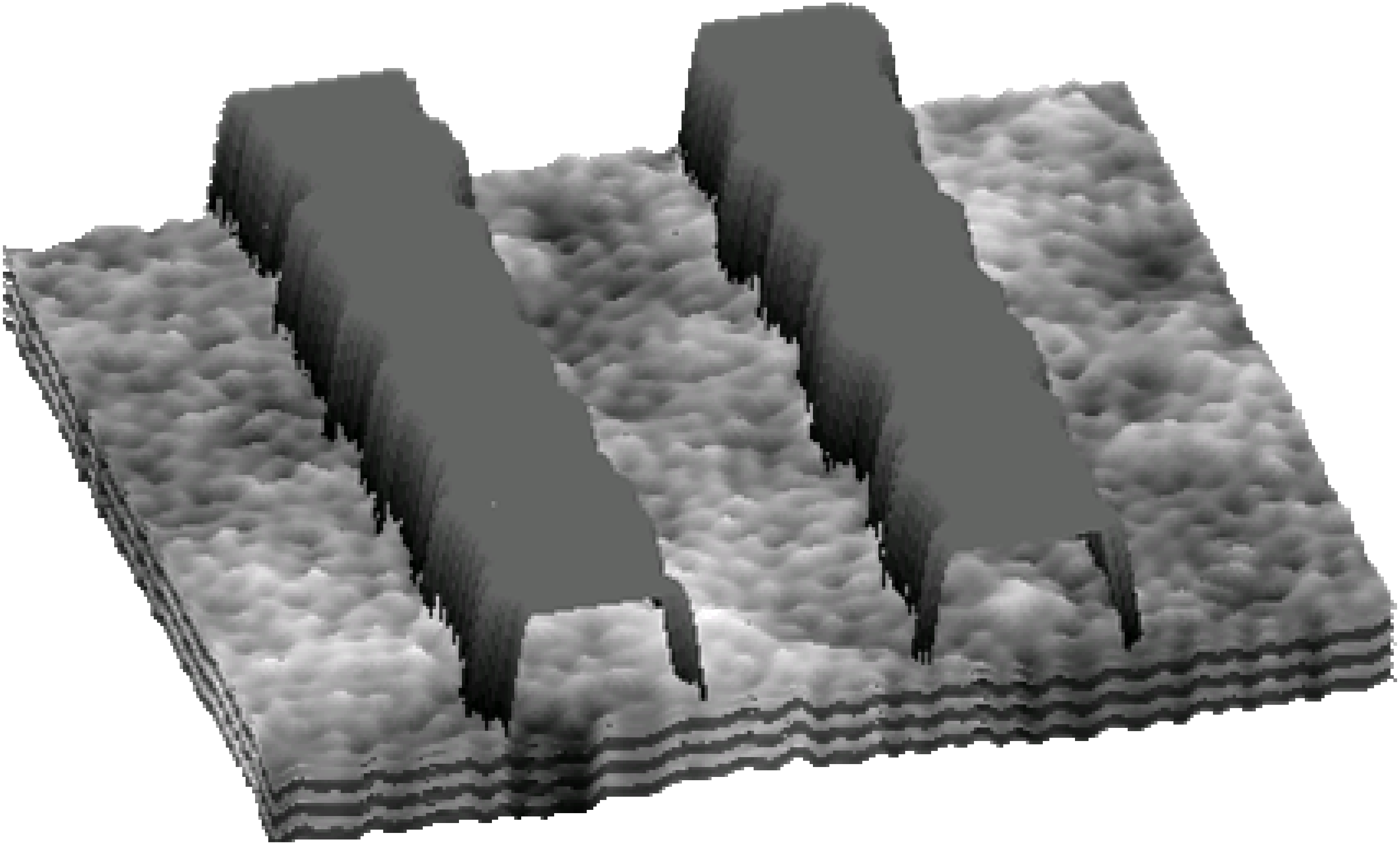
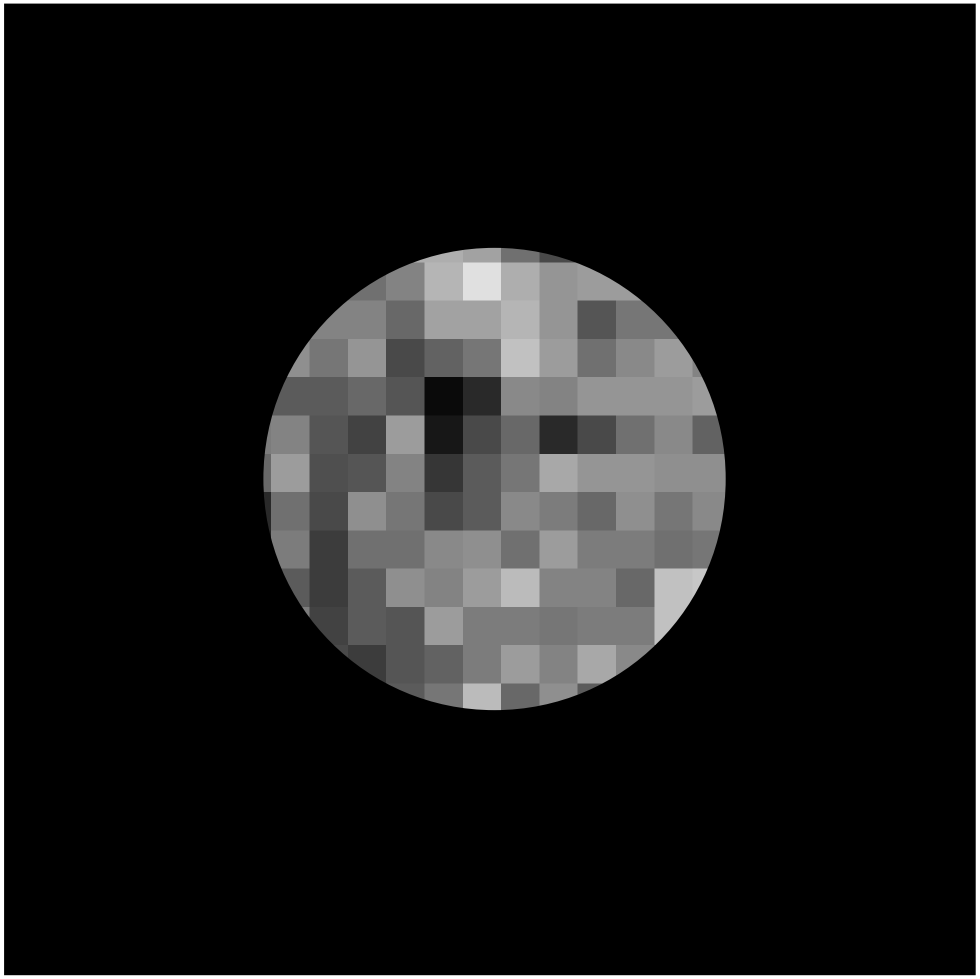
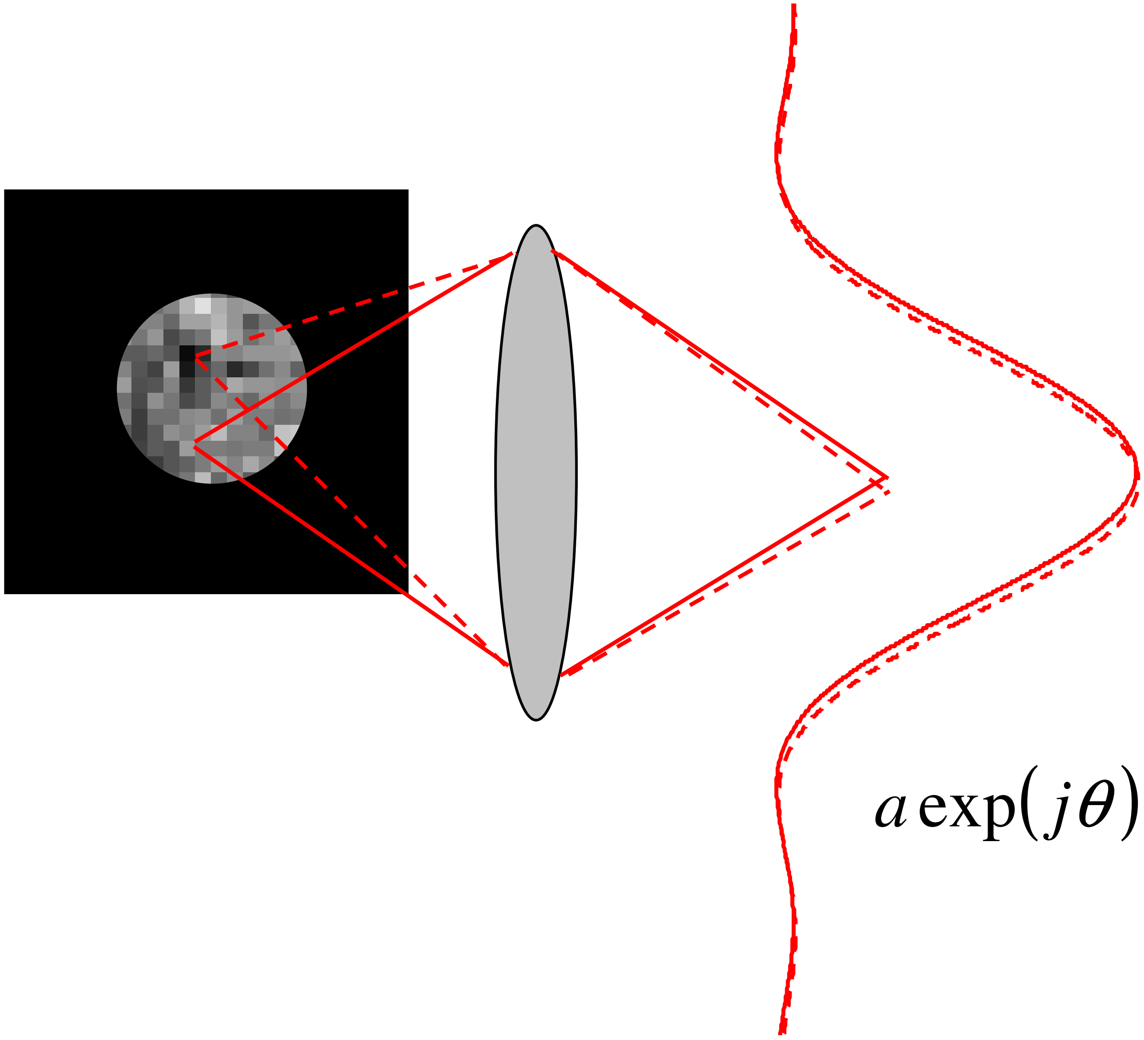
Mask roughness



Mask roughness induced speckle also impacts printed contact size variation



Randomly phased points in the diffraction-limited contact create overlapping PSFs in image plane



Total resulting field can be expressed as random walk (assume Wc > contact size)

$$a\exp(j\theta)=\frac{1}{\sqrt{N}}\sum_{k=1}^{N}\alpha_k\exp(j\phi_k)$$

Randomly phased points in the diffraction-limited contact create overlapping PSFs in image plane

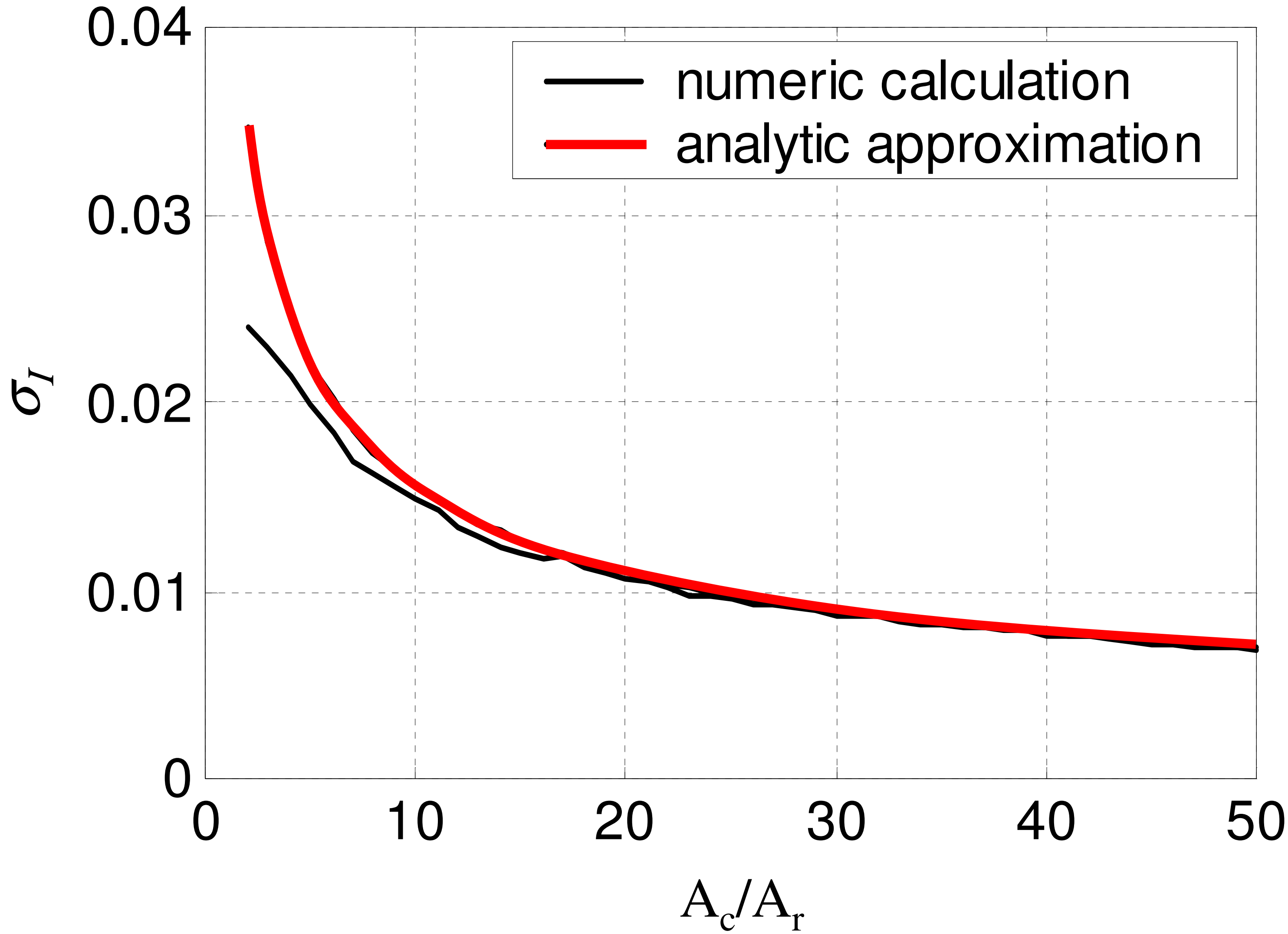
- Assume phase on mask is zero mean Gaussian random variable with variance σ^2
- Assume constant amplitude on mask
- Assume small phase errors on mask

$$\sigma_{\hat{I}} = \frac{2\sqrt{\frac{1}{2}\left[1+\exp\left(-2\sigma^2\right)\right]-\exp\left(-\sigma^2\right)}}{\sqrt{\frac{A_c}{A_r}}\exp\left(-\frac{\sigma^2}{2}\right)}$$

Image intensity standard deviation

- A_c = Area of contact
- A_r = intra-contact mask roughness correlation area

Analytic approximation holds up well even at small Ac/Ar



Contact width (W) variation linked to intensity variation through image slope

Numeric example

$$\sigma_W = \sigma_{\hat{I}} \frac{dW}{d\hat{I}}$$

Normalized aerial image slope

- 0.25 NA
- $d\hat{I}/dW$ = 0.019 nm^{-1} (based on *Prolith* modeling)
- 4x mask, 120-nm square contacts on mask (30-nm at wafer)
- 80-nm mask roughness coherence diameter
- Allow only 5% reduction in process window due to mask roughness
    - Full 10% process window tolerance = 3-nm 3σ
    - Allowable mask roughness contribution = 0.15-nm 3σ
    - Allowable σ_W = 0.05 nm

Allowable intra-contact mask roughness = 45 pm rms

~2x smaller than current capabilities

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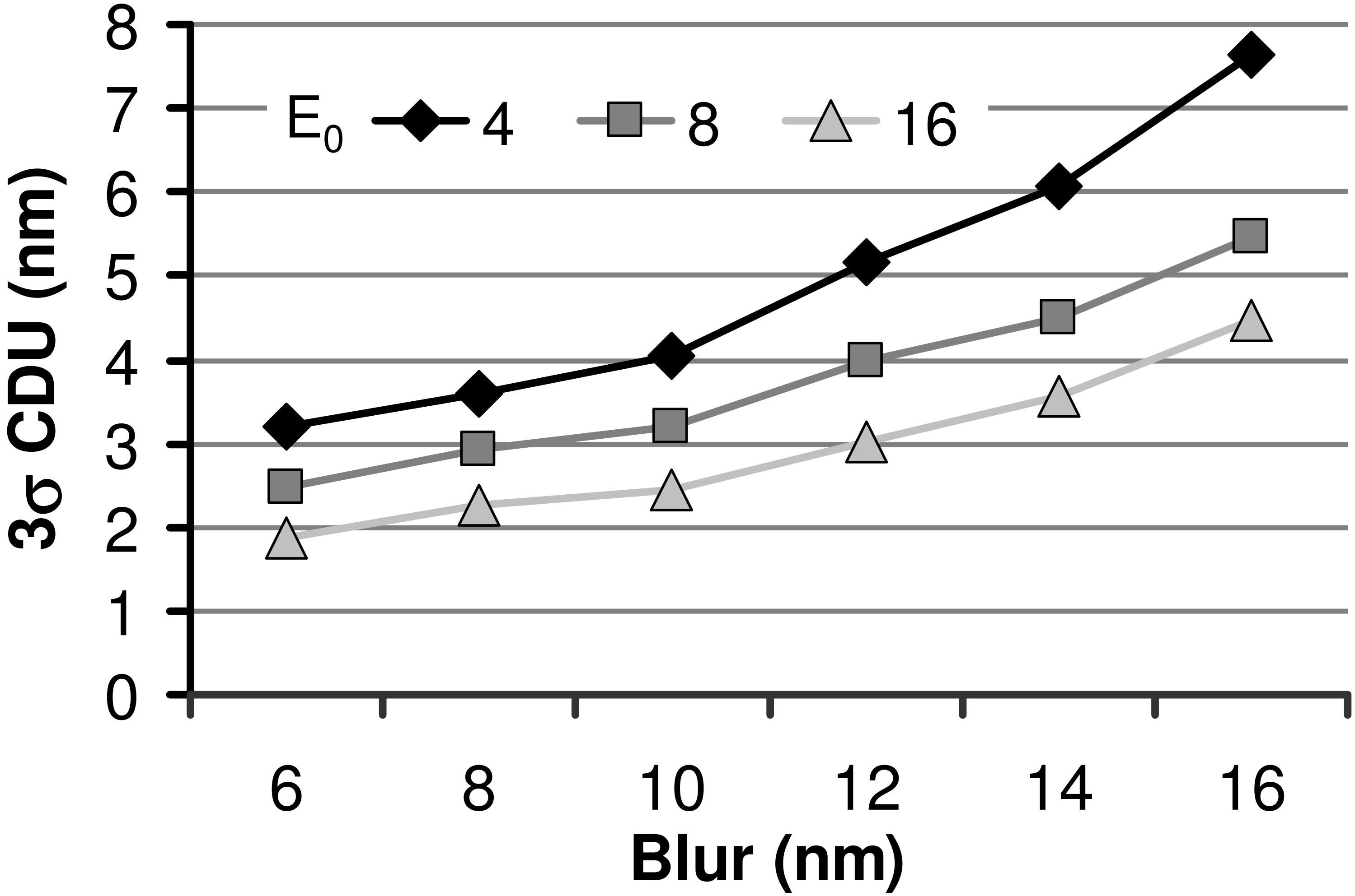
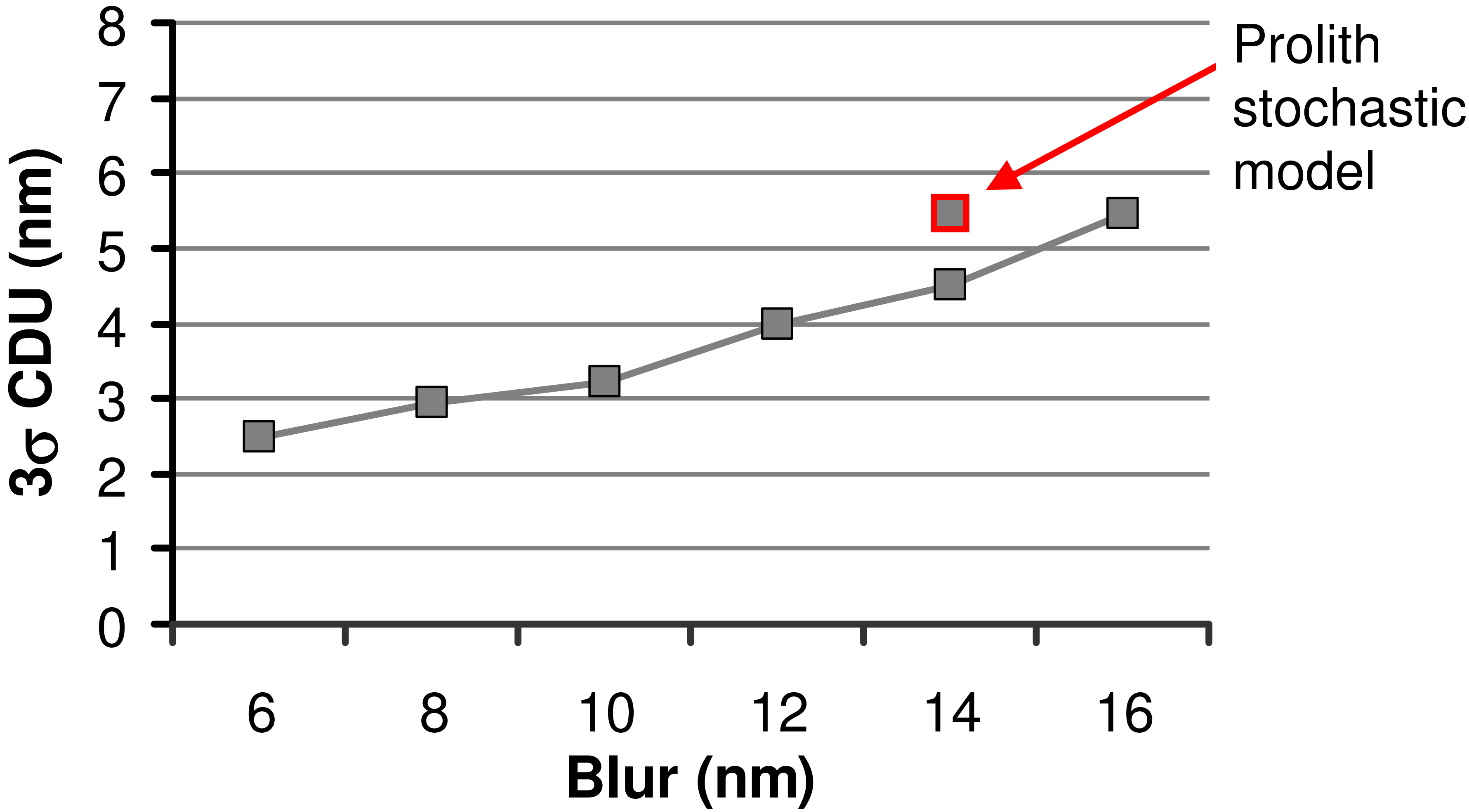
Shot noise: higher blur implies higher dose requirements

Model includes photon stochastics only (Gallatin model)



Shot noise: higher blur implies higher dose requirements



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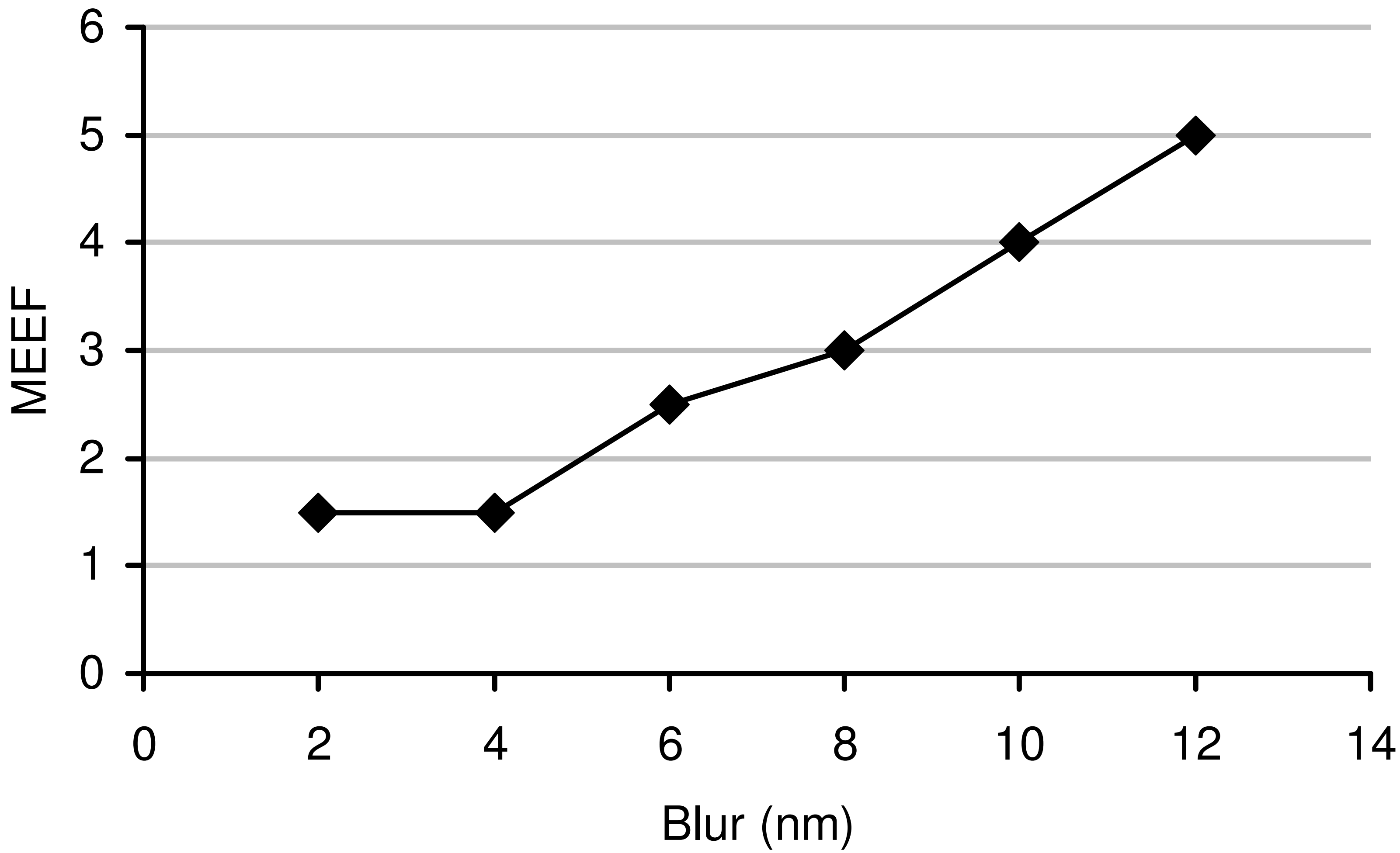
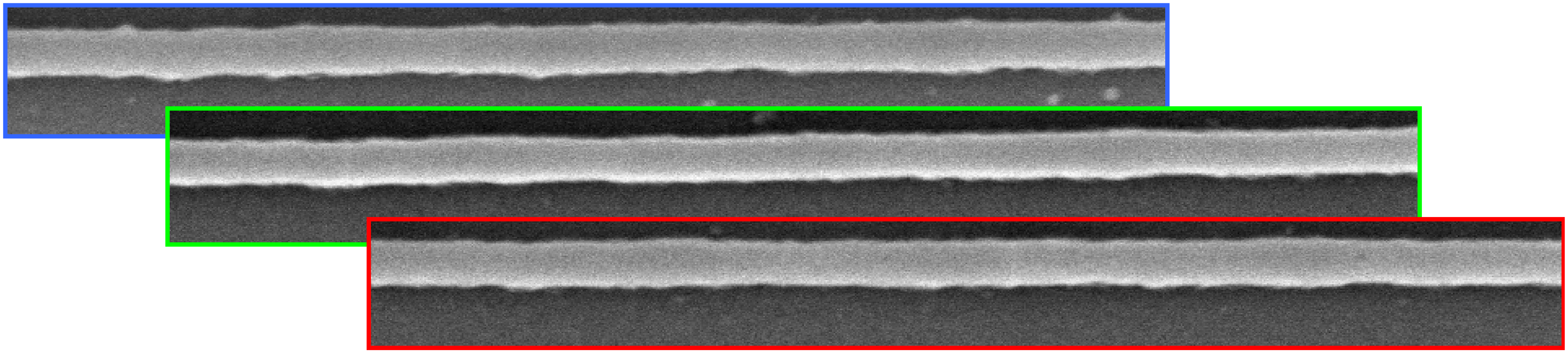
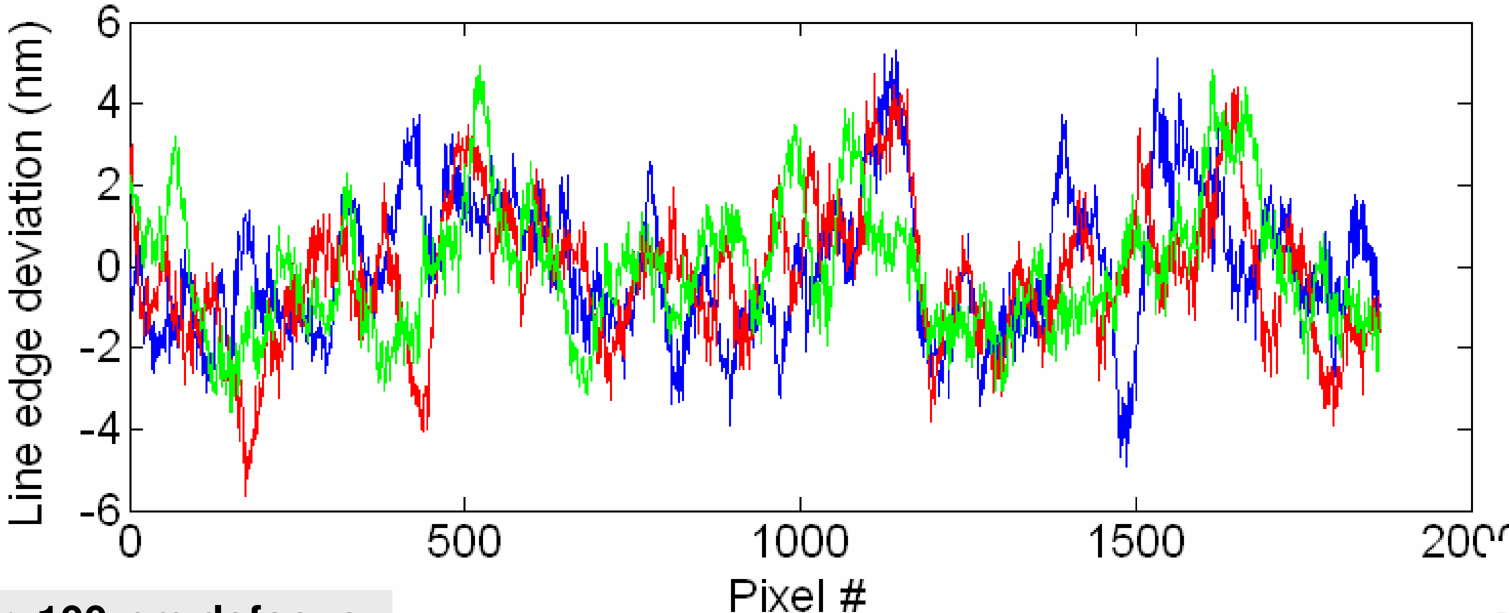
Resist blur dominant factor in total effective MEEF



Correlation measurement used to determine mask contributors to LER

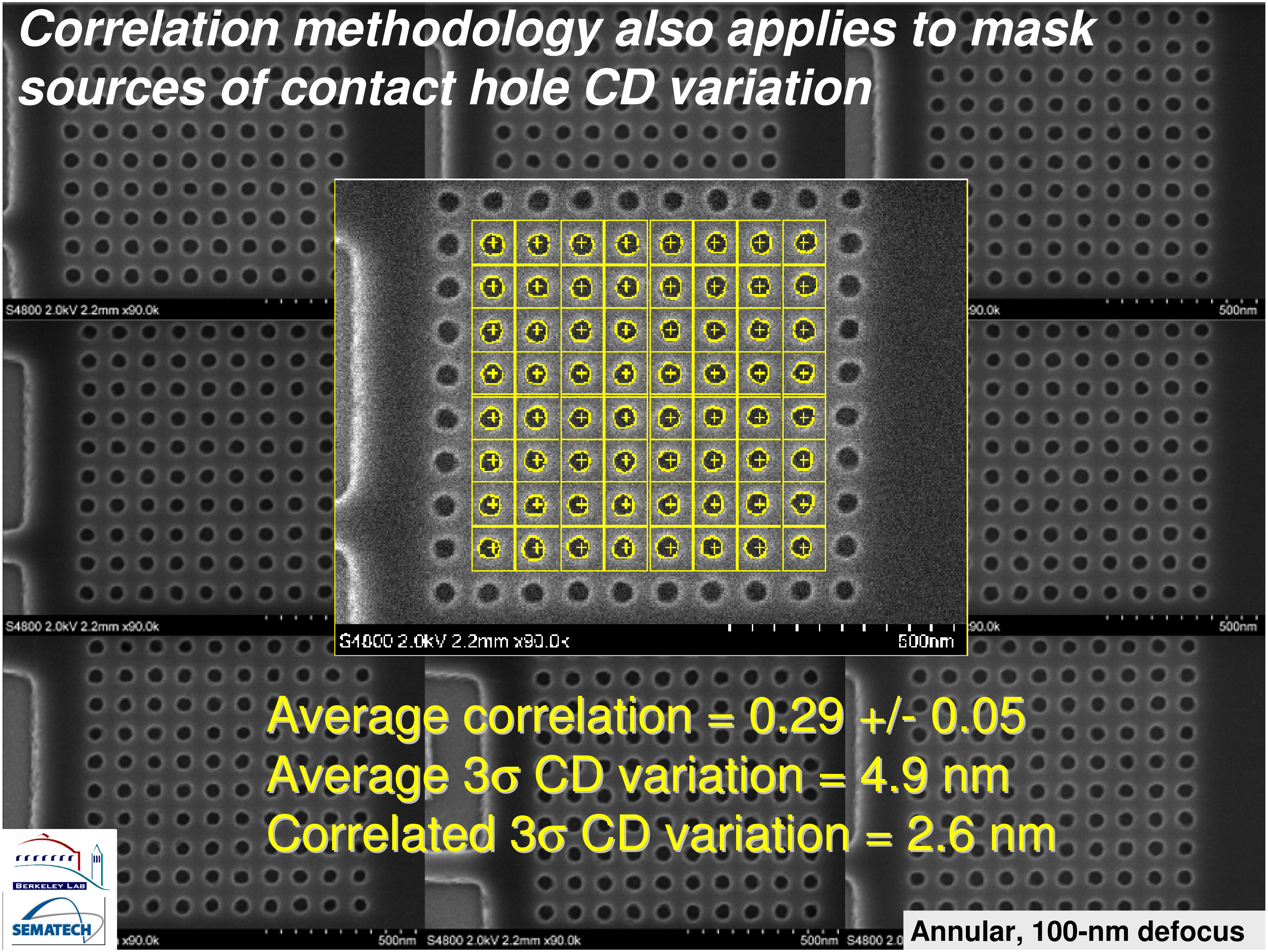


LER = 4.3 nm, Average correlation = 35%, Correlated LER = 2.5 nm



Annular, 100-nm defocus

Correlation methodology also applies to mask sources of contact hole CD variation



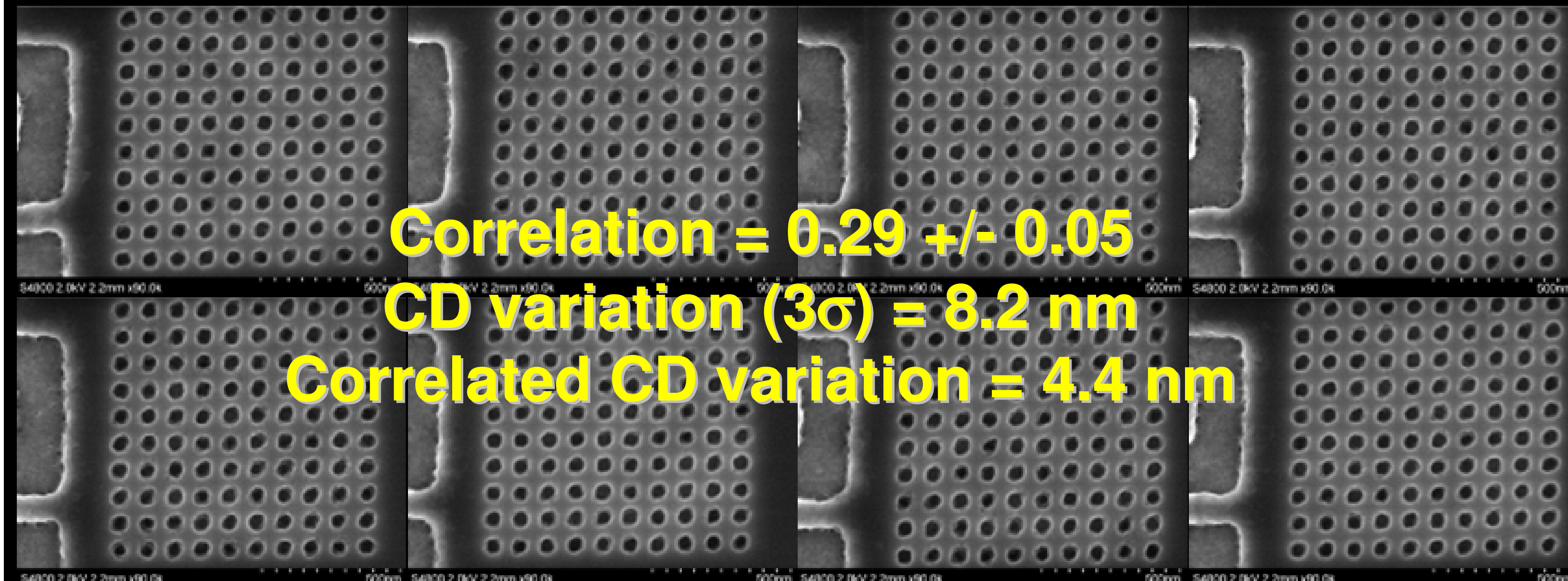
Average correlation = 0.29 +/- 0.05

Average 3σ CD variation = 4.9 nm

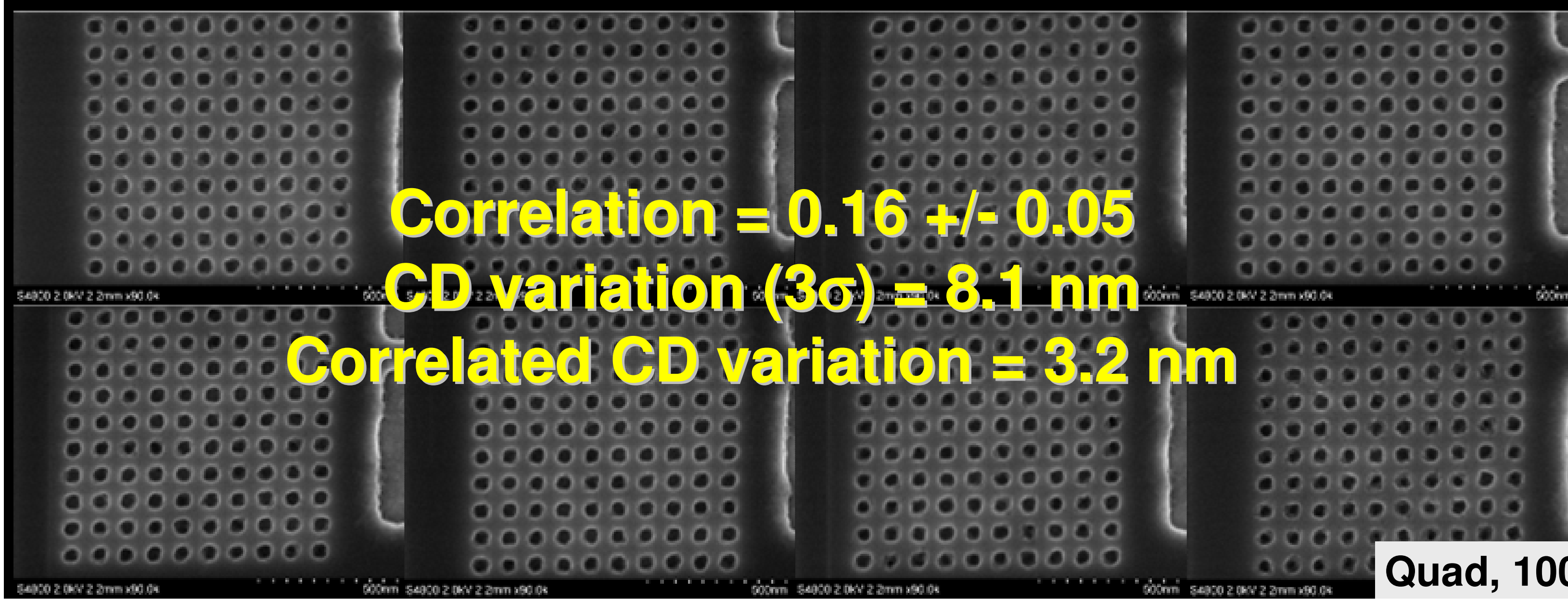
Correlated 3σ CD variation = 2.6 nm

Annular, 100-nm defocus

Correlation methodology also applies to mask sources of contact hole CD variation



Post cleaning



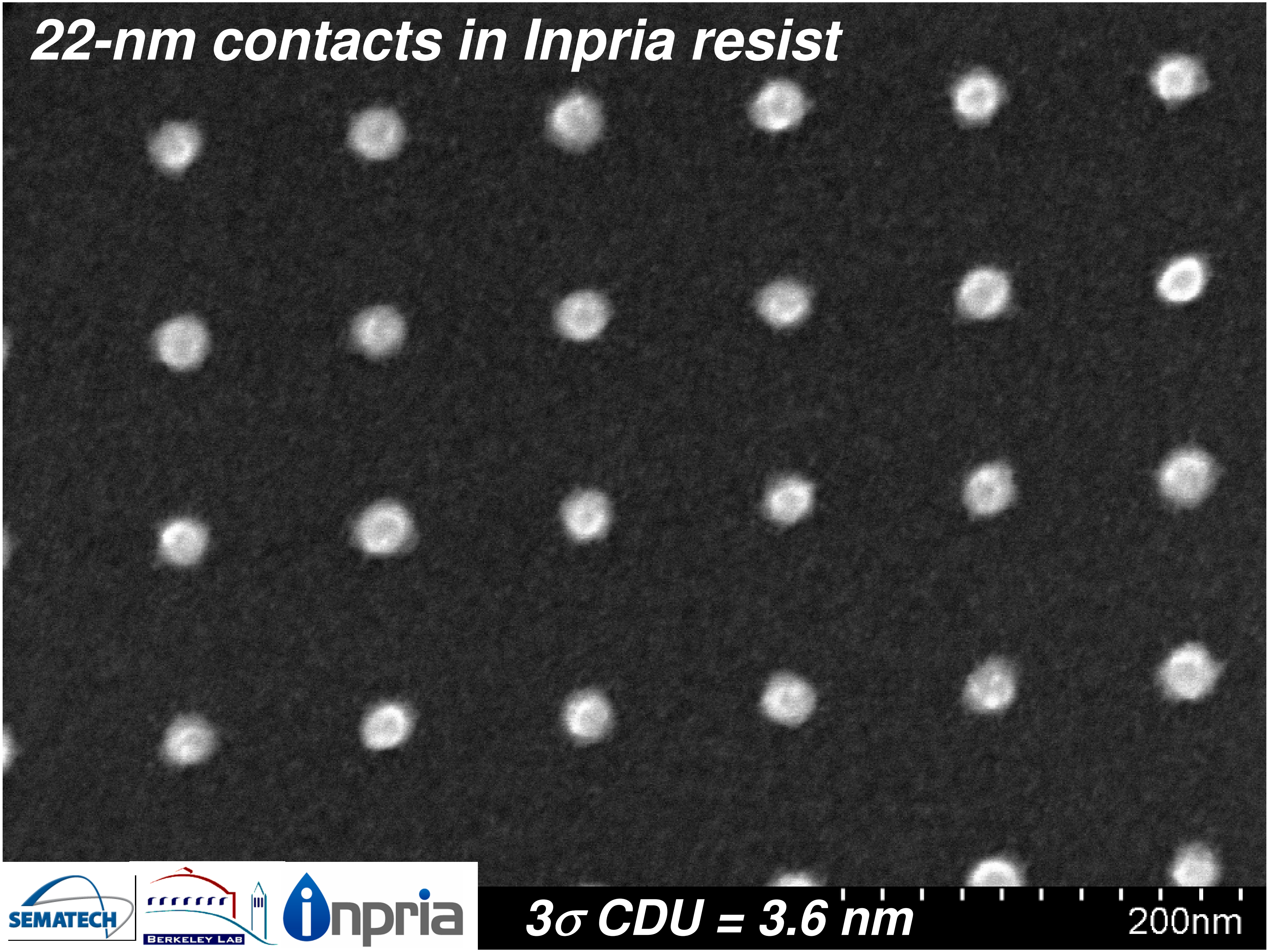
New mask

Quad, 100-nm defocus

Summary

- Mask and condenser roughness plays important in contact CDU
- Resist blur drives both dose requirements and mask specs
- Correlation methods can be used to measure mask contributions to CDU

This work was supported by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.


22-nm contacts in Inpria resist
3σ CDU = 3.6 nm
200nm
SEMATECH
BERKELEY LAB
inpria