Comparison of Techniques to Measure the Point Spread Function due to Scatter and Flare in EUV Lithography Systems

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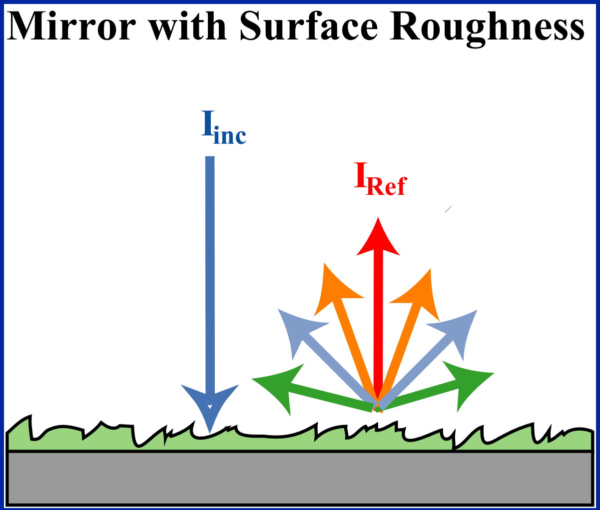
Source of flare in EUV optics

- Flare is caused by the surface roughness of optical mirrors inside the PO
  - MSFR roughness of ~0.25 nm/mirror results in >20% flare in the ETS
- Flare scales as $1/\lambda^2$
  - For the same roughness flare is ~200X larger for a 13.5 nm system relative to 193 nm.
- 75% of the flare is contained within 100 μm
  - EUV flare has shorter range than DUV flare
  - Across field intrinsic flare is uniform for EUVL tools



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Motivation

- Flare results in decrease in contrast and hence resolution and process window
  - Identifying the flare level in a stepper is critical
- Are we underestimating the flare in EUVL systems using the 2μm line to measure flare?
  - Do we need a narrower linewidth (for e.g., 0.5 μm) to measure flare?
- Point Spread Function due to scatter (PSF_{sc}) is needed to predict CD variation and application of Flare Variation Compensation (FVC)
  - How do we verify that the PSFsc is accurate to be used in Flare Variation Compensation (FVC)?

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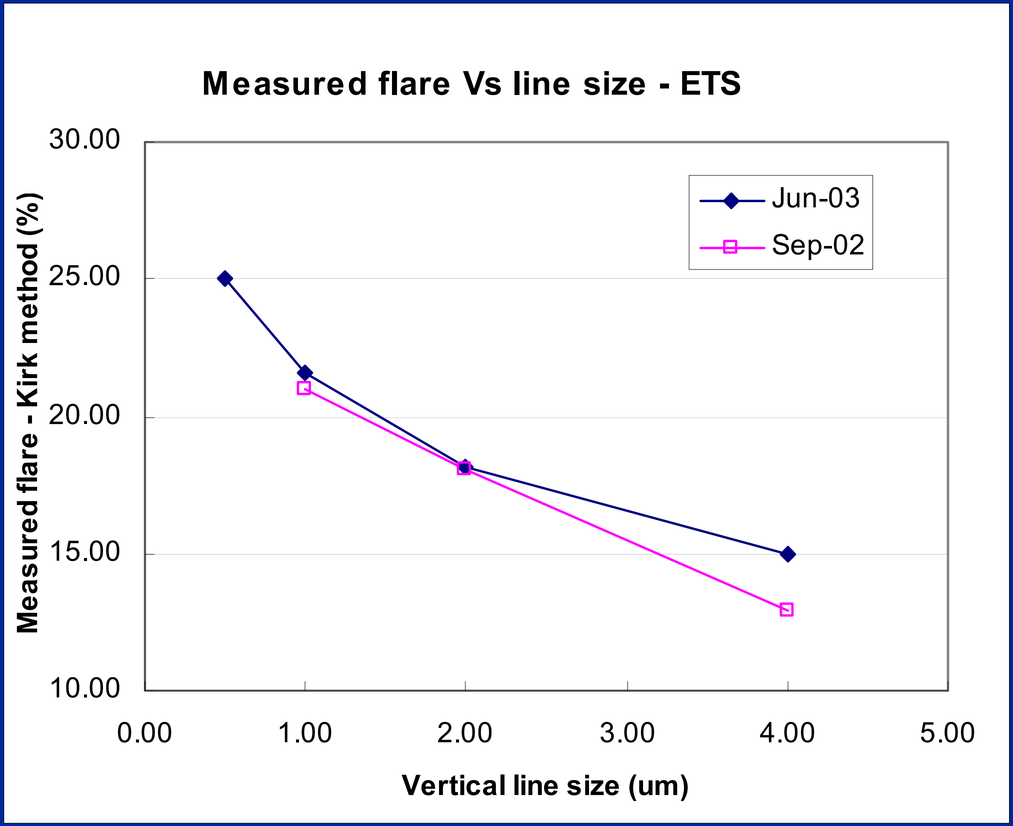
Measured flare on the ETS Vs feature size



All data taken off vertical lines, 25 um from the end

Sep-02 data: refer S. Lee et. al., Proc. SPIE vol. 5037, 2003

- **Flare measured by the 2 μm line (18%) is lower than flare measured with a 0.5 μm line (25%) by a factor of 1.4**
- **We would like the measured flare values to be as close to the intrinsic flare as possible**

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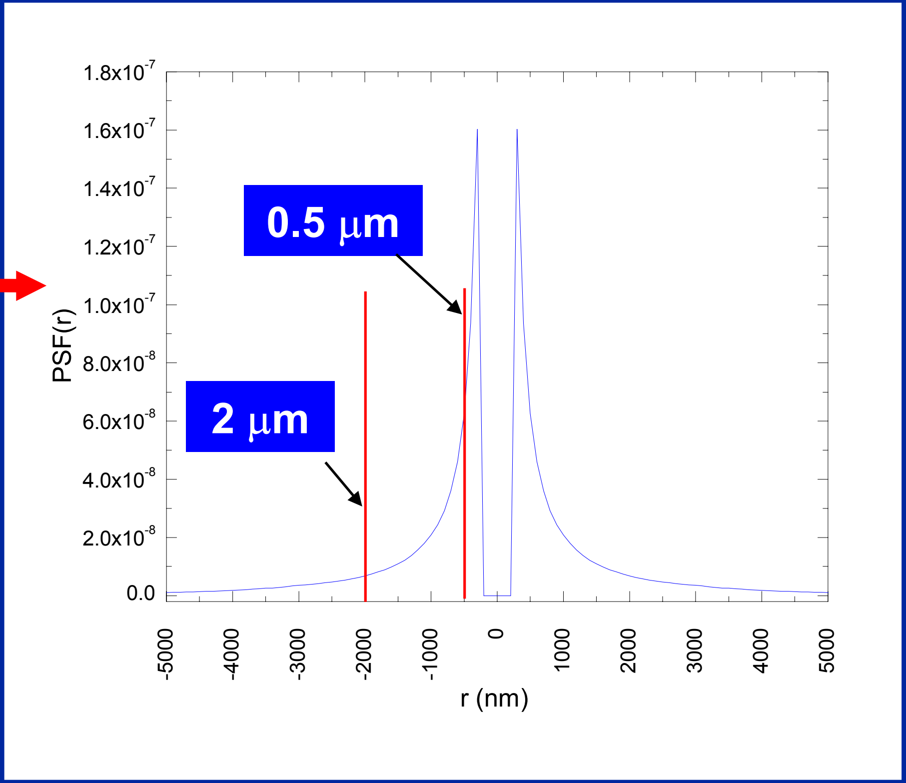
Why is flare measured by a 2 μm line less than flare measured by a 0.5 μm line ?

- Open frame flare within 2 μm = 4.3%whereas that within 0.5 μm = 0.04%
- The PSF_{sc} drops by an order of magnitude from 0.5 μm to 2 μm
- The flare is calculated by convolving the PSF_{sc} with the layout and hence any chrome in the pattern will reduce the flare
- The chrome from the 2 μm line appears to be locally reducing the measured flare

PSFsc for POB2



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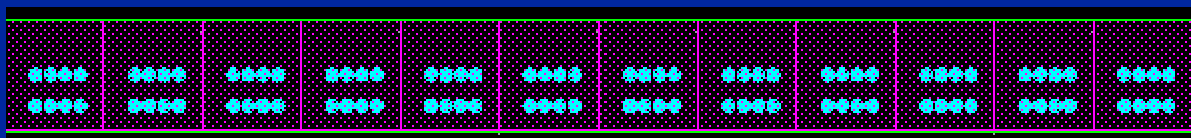
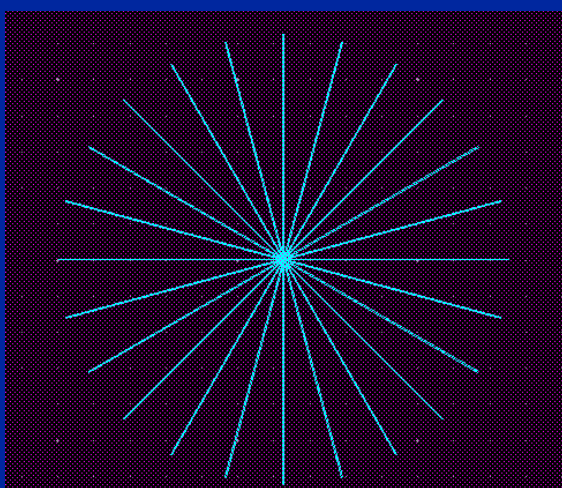
Flare measurement – Kirk test using spoke pattern

Across the field 24 mm (12 copies)

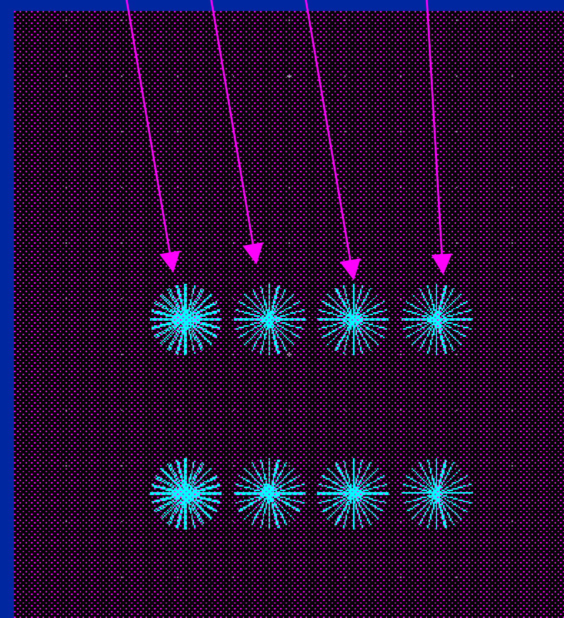


250 μm

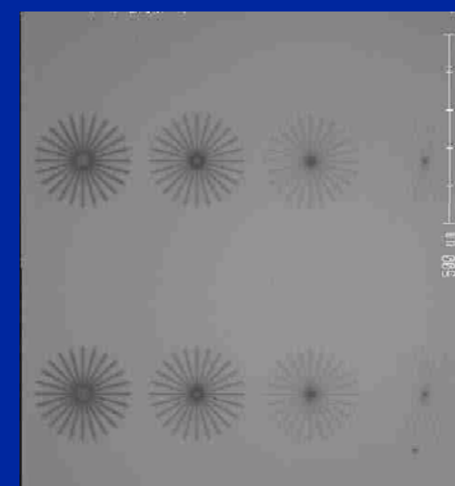


Spokes are at 15 degree increments

4 μm, 2 μm, 1 μm, 0.5 μm wide lines

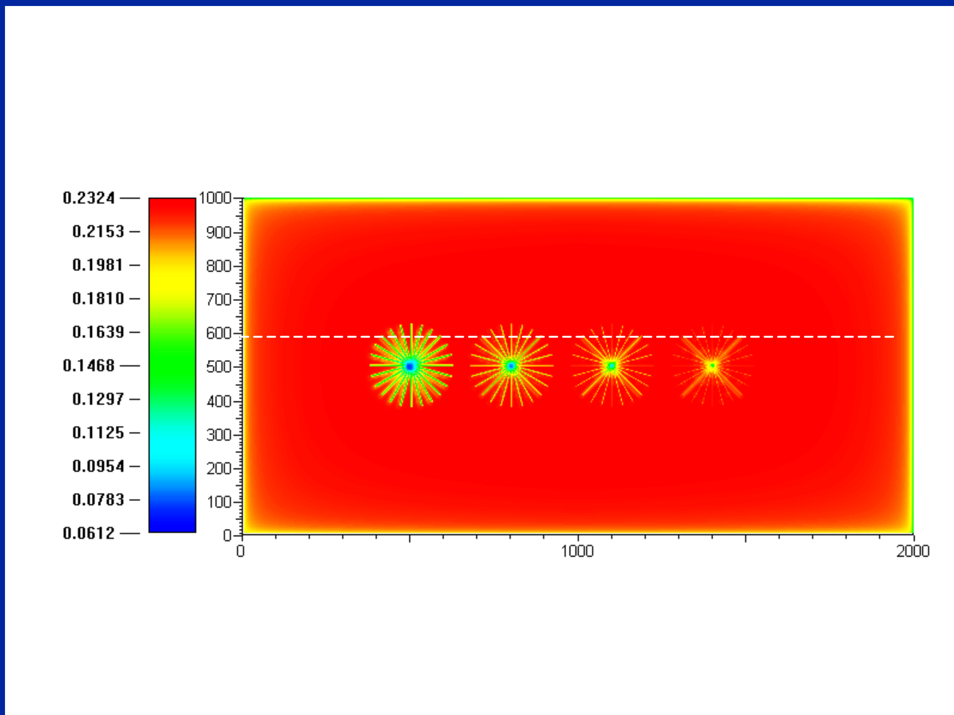


Print test result

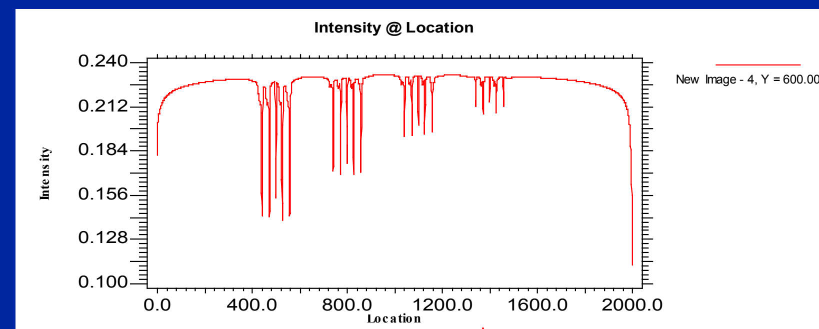


Flare = E_0/E_{clear} where E_{clear} is the dose to clear a given feature

Calculating the flare with spoke patterns by convolution with the PSF_{sc} from mirror roughness



Flare along cut line



Units are um

Line size (um)	Calculated flare %
4.0	14.7
2.0	17.4
1.0	19.9
0.5	21.8

- **A factor of 1.3 difference between calculated flare below the 2 μm line and the 0.5 μm line**
- **Reasonably good agreement with measurements**

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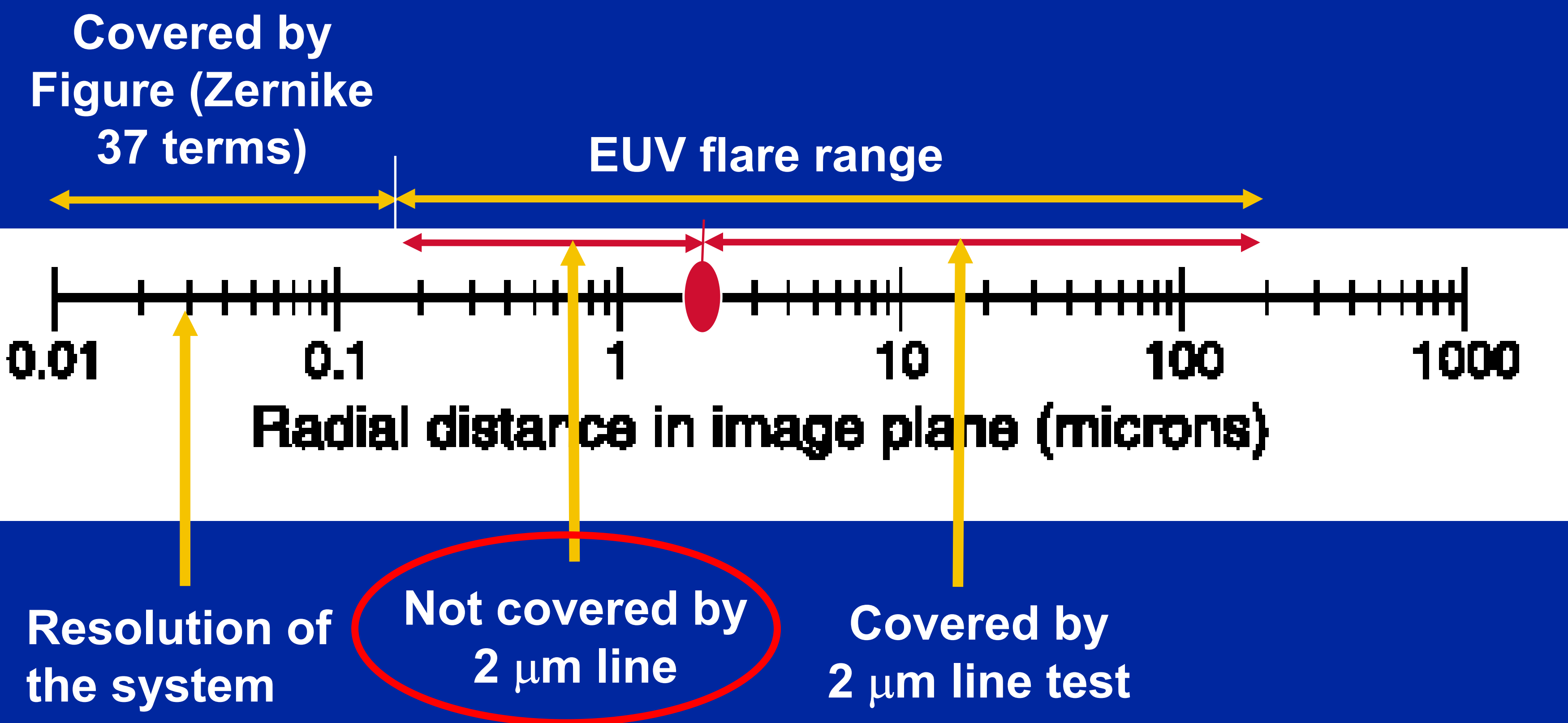
Need smaller line size to measure EUV flare



- Using 2 μm line to measure flare may neglect a large portion of the scattering contribution

Case to make 0.5 μm line as the standard for measuring flare in EUVL steppers

Does the 0.5 μm line meet the requirements to be used for measuring flare ?

- $k_1 = 3.75$[1] $\therefore$ Line size >> the diffraction limit ✓
- Resist thickness $\leq$ 120 nm. Line size > 4X resist thickness and hence not impacted by lateral dissolution rate ✓
- Line size small enough to not mitigate flare, hence more representative of the intrinsic flare ✓
- Provided the line length > 10 μm, the error in the flare contributed from the Airy disc PSF is negligible ✓

[1] For $\lambda = 13.4$, NA = 0.1

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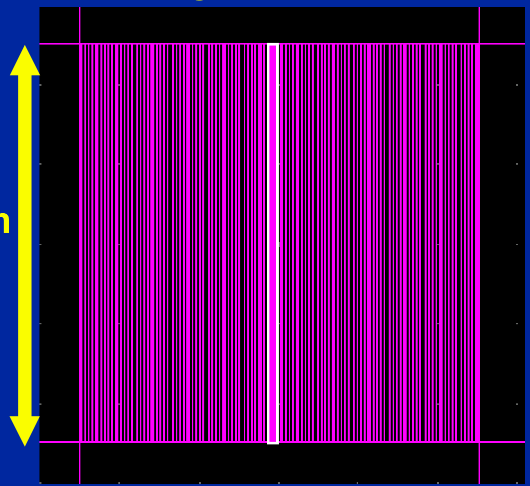
Method of verification of the PSF_{sc} from roughness – Calculating flare variation

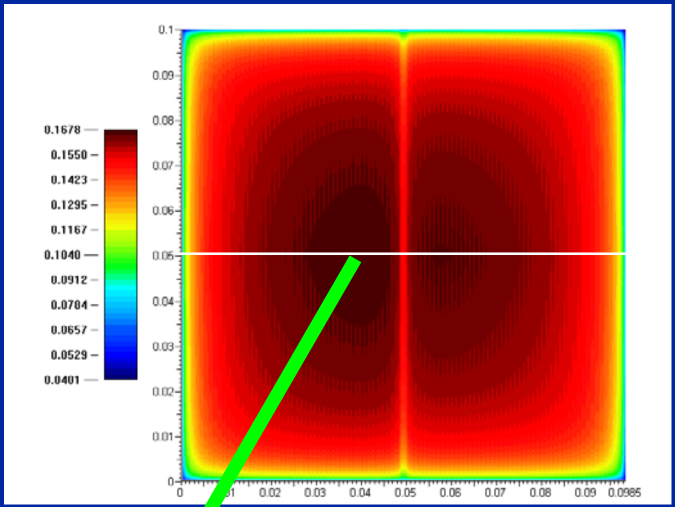
Test pattern: 75 nm line, 1 µm pitch, surrounded by sea of chrome

100 µm



Convolution with the Point Spread Function from roughness

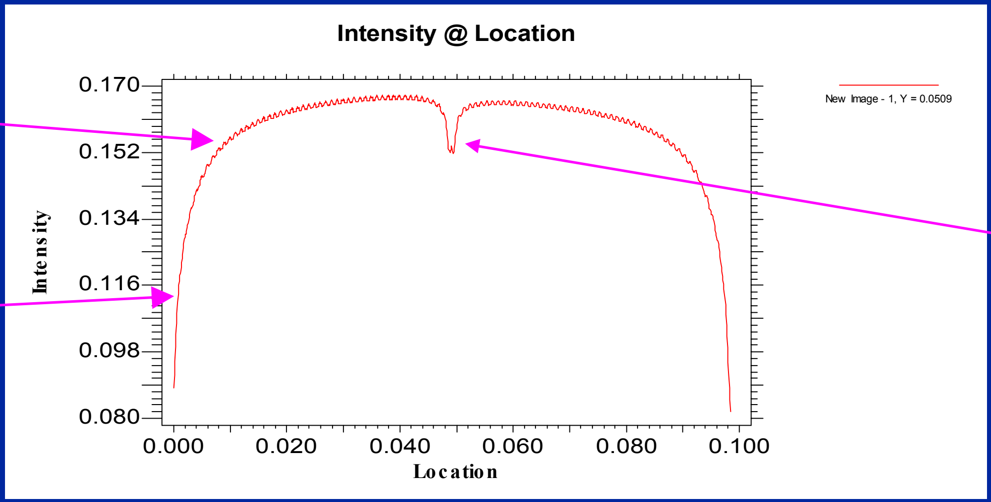
Calculated flare variation



Cutline showing flare variation

12 µm from edge, 15.8% flare

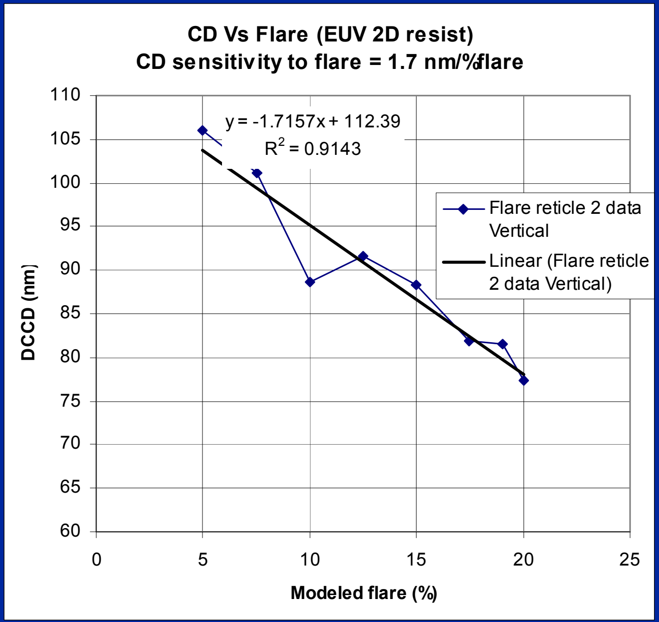
1 µm from edge, 10.5% flare

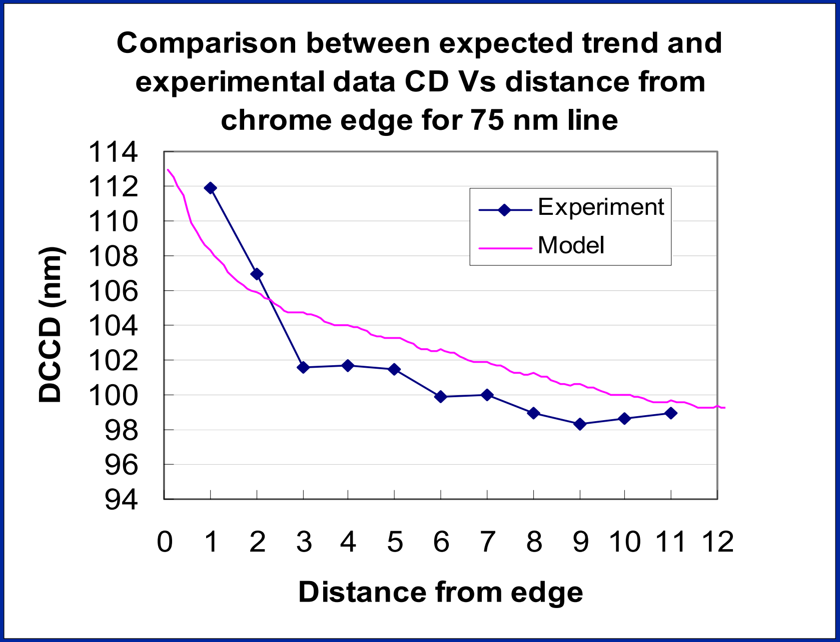


Location of 0.5 µm line to measure flare

Validation of modeled CD variation using flare variation modeled with PSF_{sc} from roughness

Modeled CD variation = Flare variation (from previous slide) X measured CD sensitivity to flare





- Flare range = 6%, CD range = 13 nm, 1.7 nm/%flare measured CD sensitivity to flare
- Since the model using the PSF_{sc} from roughness matches the experimental data reasonably well, the PSF_{sc} from roughness is suitable to use for Flare Variation Compensation (FVC)

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Alternative method of extracting the PSF_{sc} from the MTF - Theory

- For an incoherently illuminated object, the Fourier transform of the PSF is the Optical Transfer Function of the system (in our case stepper and resist)
- In 1D, the Fourier transform of the Line Spread Function (LSF) is given by

$$\mathrm{F}\left[\mathrm{LSF}(x)\right] = \mathrm{M}(k_x)\exp[i\Phi(k_x)]$$

where

  - $\mathrm{M}(k_x)$ is the Modulation Transfer Function (MTF), and
  - $\Phi(k_x)$ is the Phase Transfer function (PTF)

- Hence, if $\mathrm{M}(k_x)$ can be measured, then the LSF can be obtained by taking the inverse Fourier Transform of $\mathrm{M}(k_x)$
- LSF has contributions from aberrations (high spatial frequencies), resist, and scatter (low spatial frequencies)

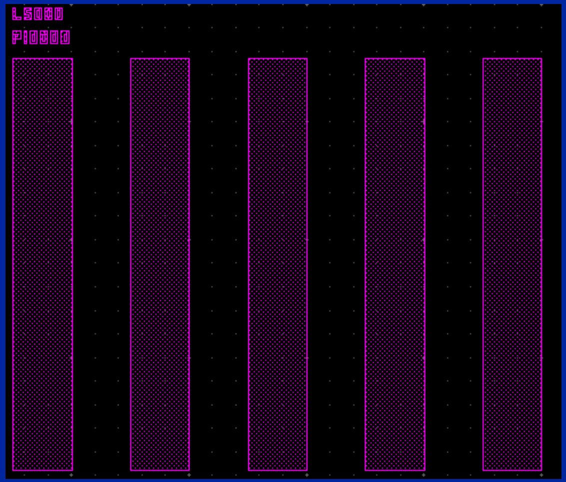
$$\mathrm{LSF} = \mathrm{LSF}_{aberr+resist} \otimes \mathrm{LSF}_{scatter}$$

Note: For simplicity, we will refer to the LSF as the PSF

Experiment to measure the PSF

- Equal line space patterns (100 nm to 20 μm pitches)
  - Only the pitches above ~5λ/NA (670 nm) contribute to flare.
- The MTF can be measured using the clearing dose (D_c) and appearing dose (D_a) of line-space gratings for a particular spatial frequency

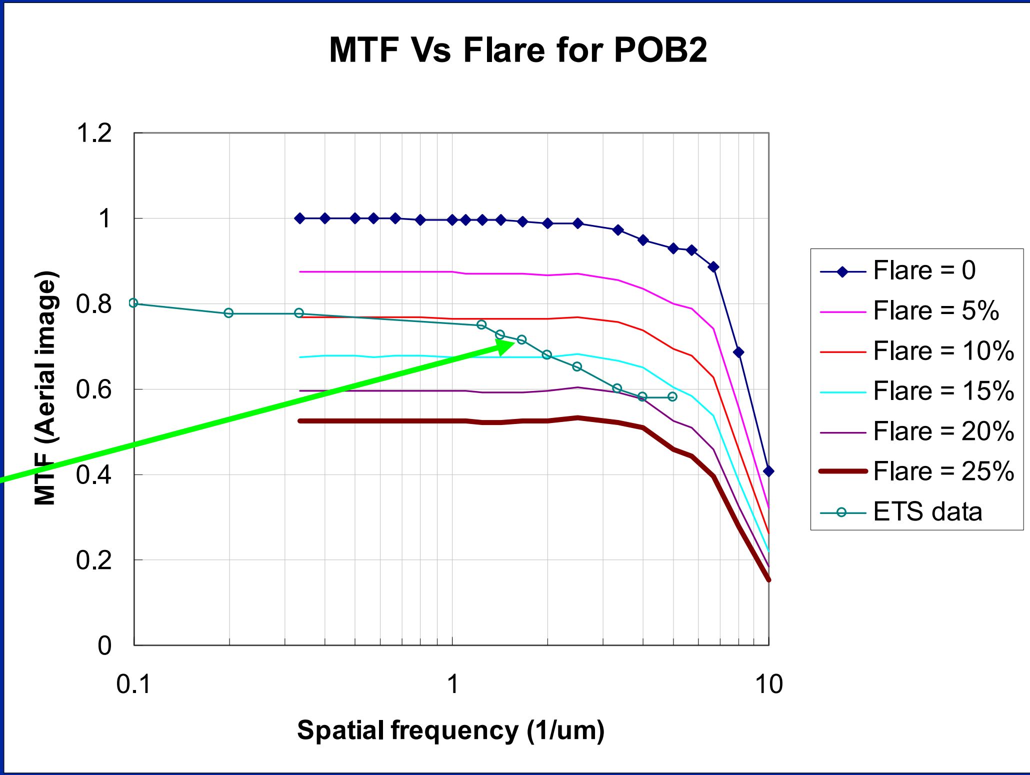
$$M(k_x) = \frac{[D_c(k_x) - D_a(k_x)]}{D_c(k_x) + D_a(k_x)}$$



- Note: The PTF $\Phi(k_x)$ can be measured by locating the center of the lines and compare the center shift with respect to a reference - but was not measured here

Results – comparison of measured MTF Vs aerial image model

Contrast degradation due to defocus, higher order aberrations, and resist effects



- Contrast measured at low spatial frequencies is higher than expected from ETS (> 20% flare) because of flare mitigation by 1:1 chrome features

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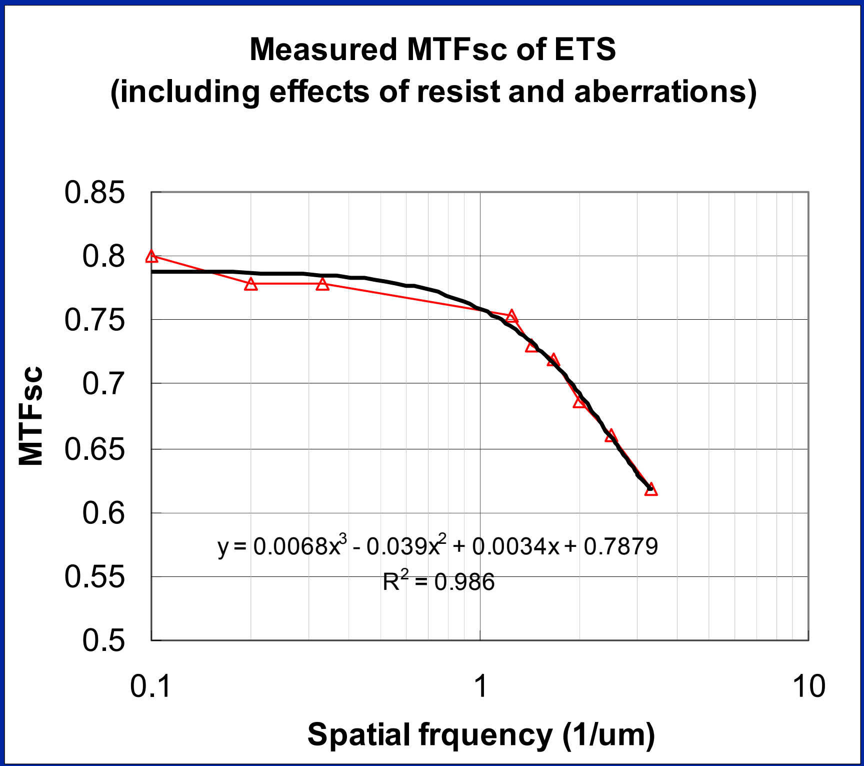
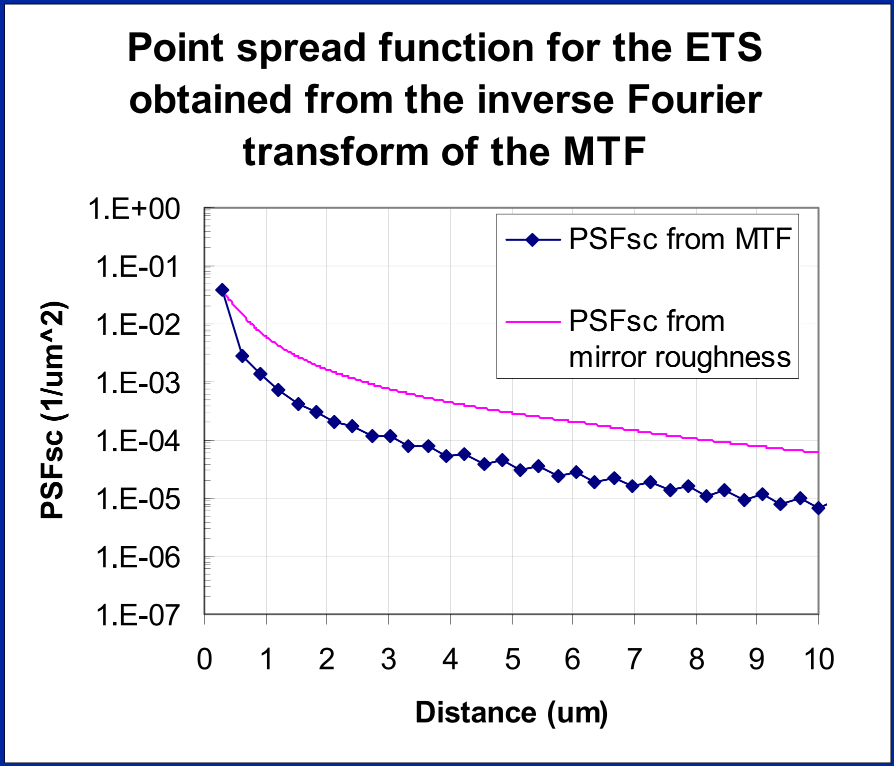
Results – comparison of PSF_{sc}





- Trend in PSF_{sc} from Modulation Transfer Function (MTF) is similar to that from mask roughness
- Structures used to measure the (MTF) mitigate the flare resulting in a lower measured PSF_{sc}
  - Recommend limiting chrome size to 0.5 µm, pitch varying

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Summary

- It is recommended that the 0.5 μm line be used as the standard to measure flare in the field for EUVL tools since it is closer to the intrinsic flare value
- Based on the experiments on the ETS, the PSF_{sc} from roughness is sufficiently accurate to do Flare Variation Compensation (FVC)
  - However, the PSF_{sc} trend needs to similar from tool to tool for FVC to be feasible for HVM
- Lithographic measurement of the PSFsc using the resist clearing method has been demonstrated on the ETS.
  - The MTF method to extract the PSF_{sc} needs to be modified for EUVL tools to minimize the flare mitigation by large chrome features

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