Gray Assist Bar OPC

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Motivation for Experiments

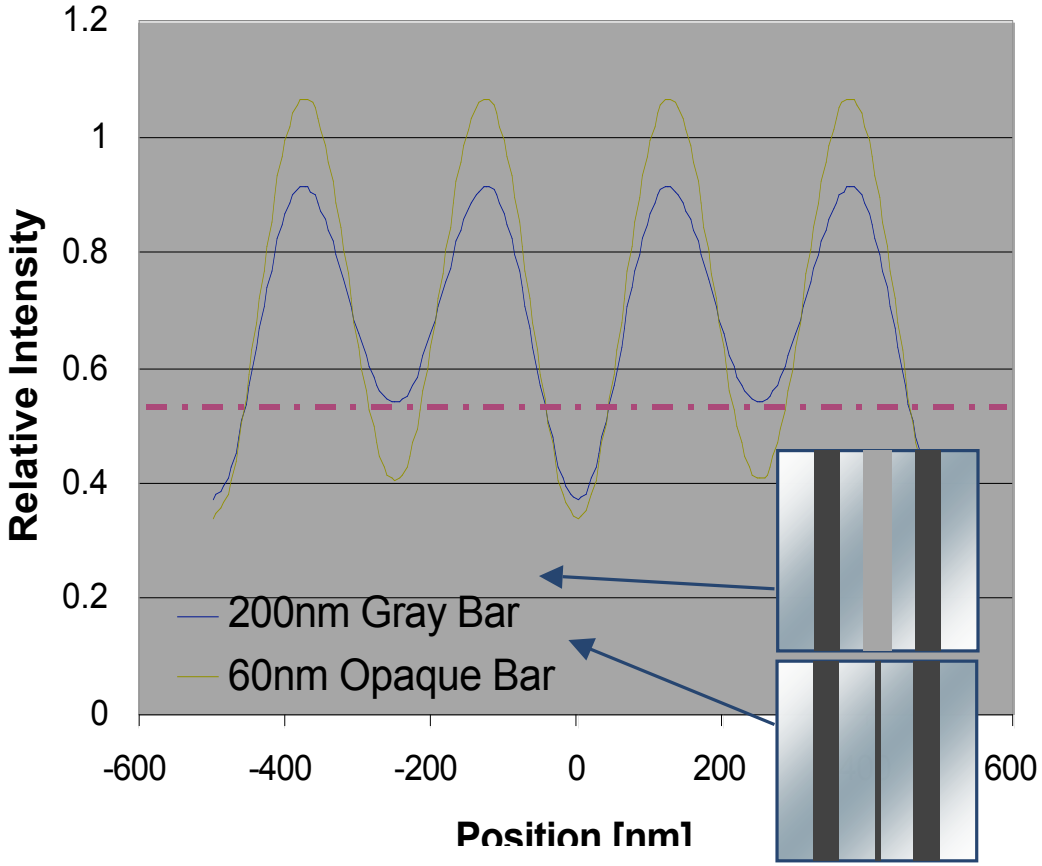
As the OPC effect of a scatter bar increases, so can its printability.

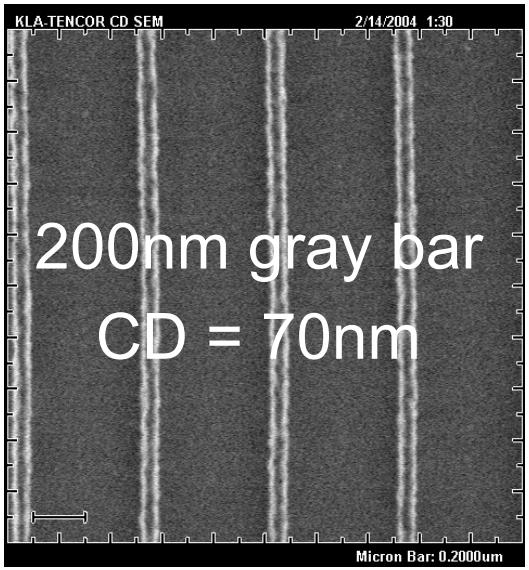
Scatter Bars, or SRAFs, enhance a main feature's resolution when placed at harmonics of the main bar's pitch.

Reducing the transmission of a typical opaque scatter bar can maintain the OPC effect while reducing its printability.

Why Gray Bars?

With Gray Bar OPC, some of the printability of conventional opaque bars can be avoided.





Outline

Introduction

Mask making

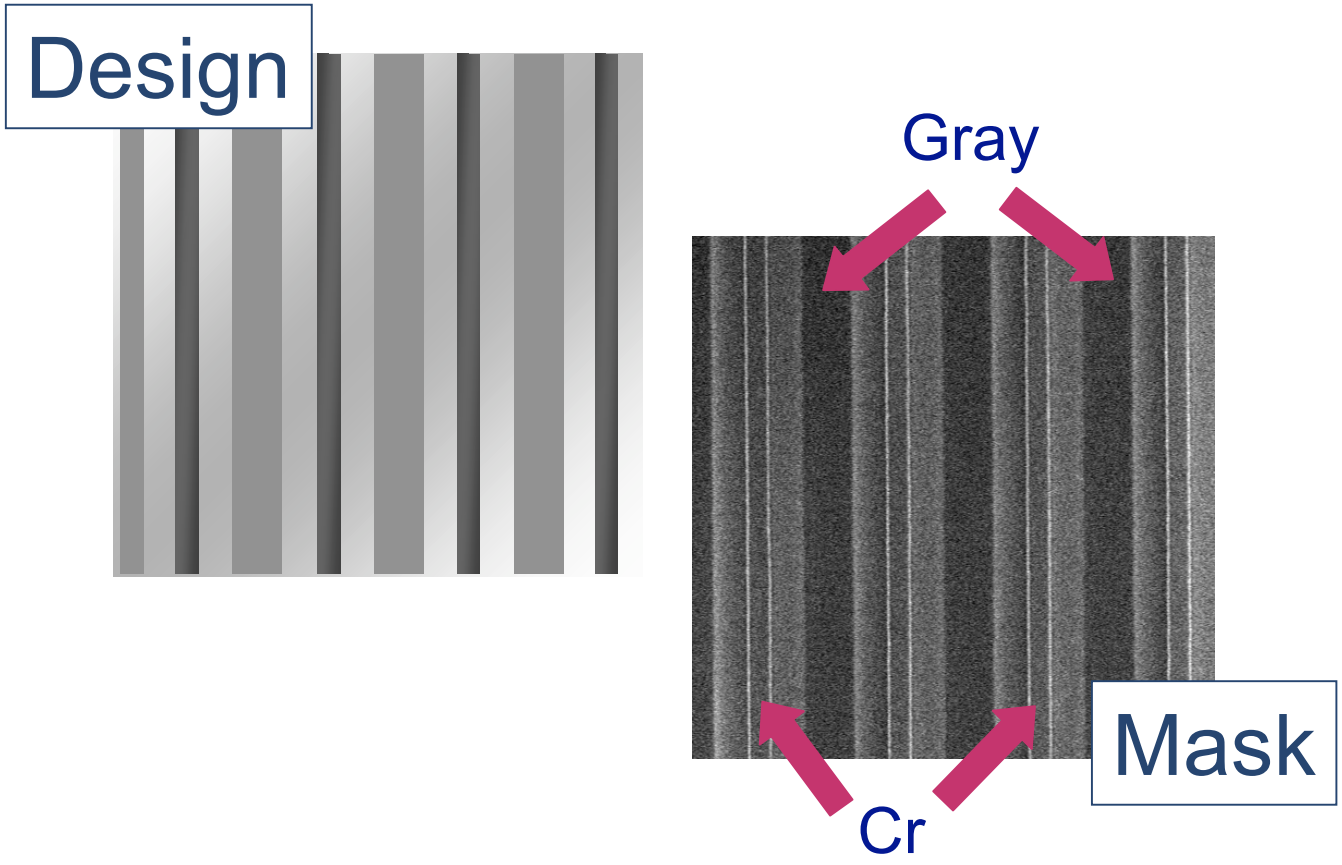
Experimental data

- Proximity Correction
- DOF Improvement
- Through pitch process window optimization

Conclusions

The Reticle - Design

- Main features (Cr-lines) are 70nm (1x) at various pitches
- Cr bias and gray assist bar width are varied for each pitch (up to 90 variations per pitch)

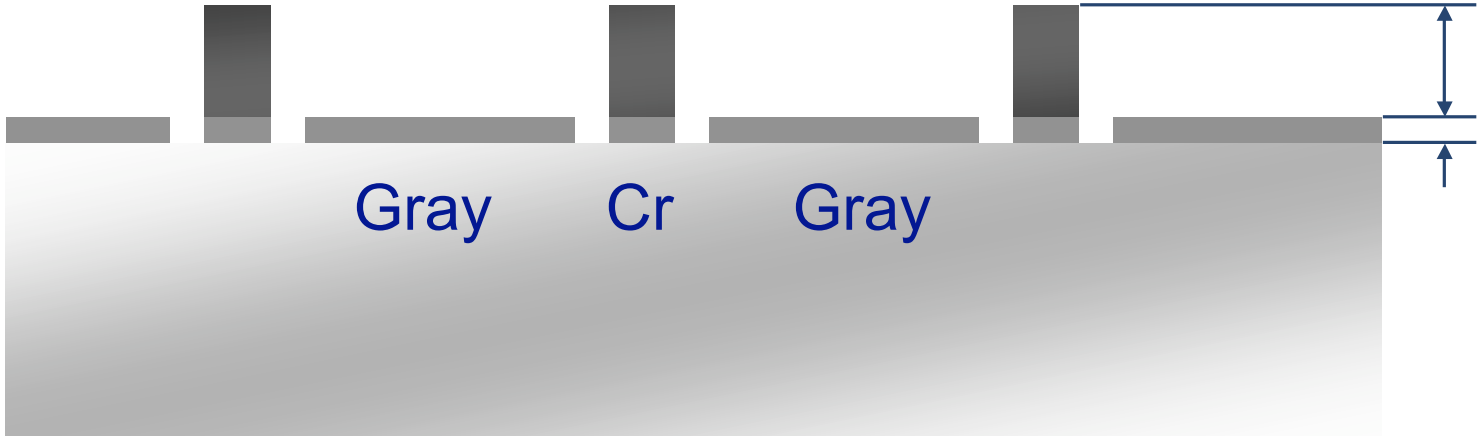


The Reticle - Manufacturing

Manufactured by Photronics

2 lithography steps

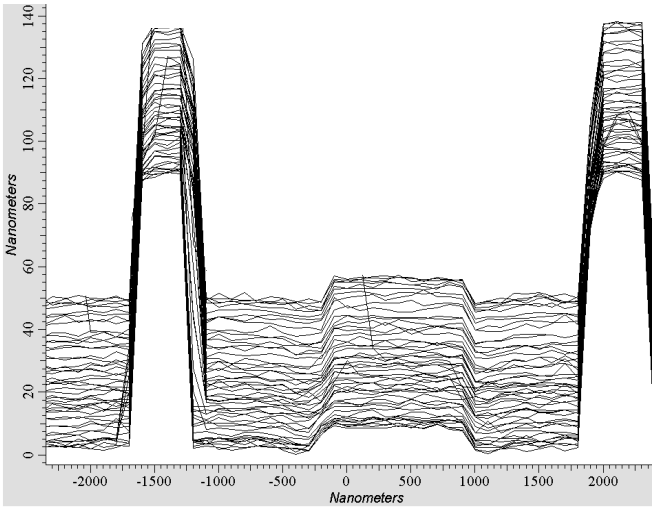
- Self-Aligned Process

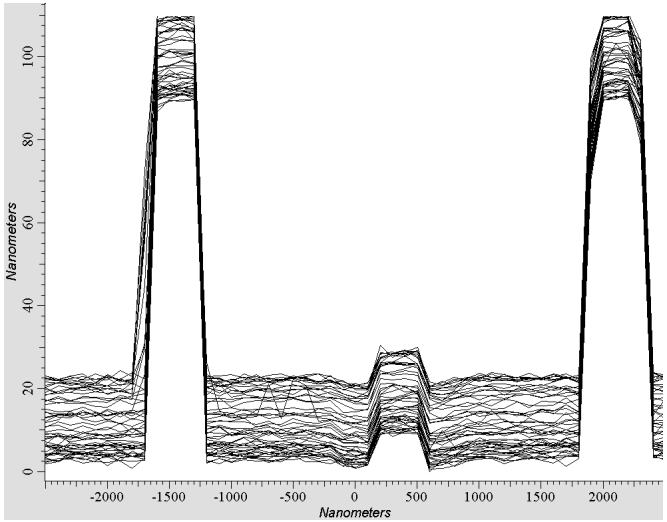


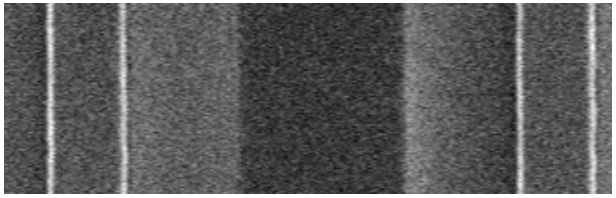
The Reticle – Profile

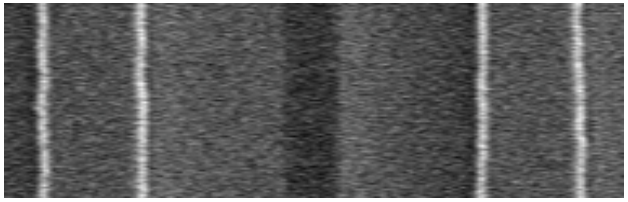
Profilometer scans of gray assist bar and Cr

- 900nm pitch
- 2 different assist bar cases







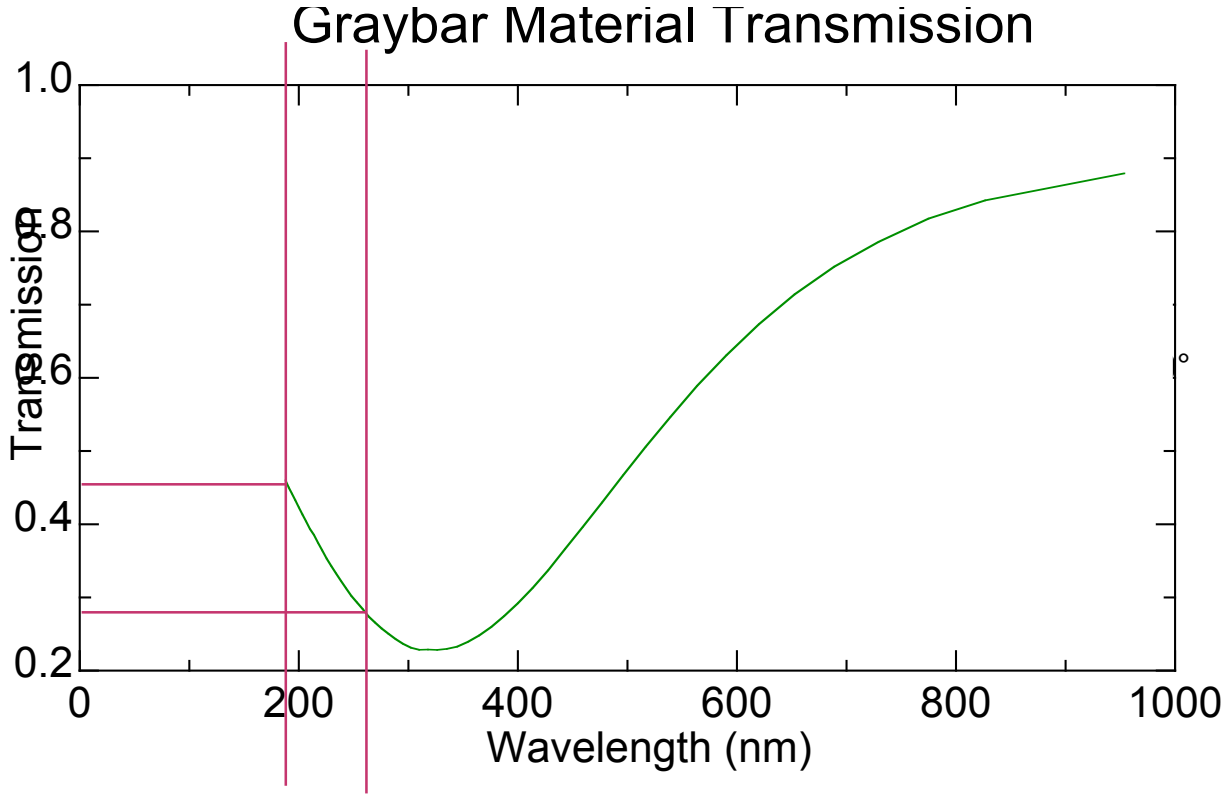


Graybar Optical Analysis

Intrinsic graybar transmission at 193 = 44.2%

Fused silica blank transmission at 193 = 90.2%

Relative transmission of Graybar at 193 = 49.0%

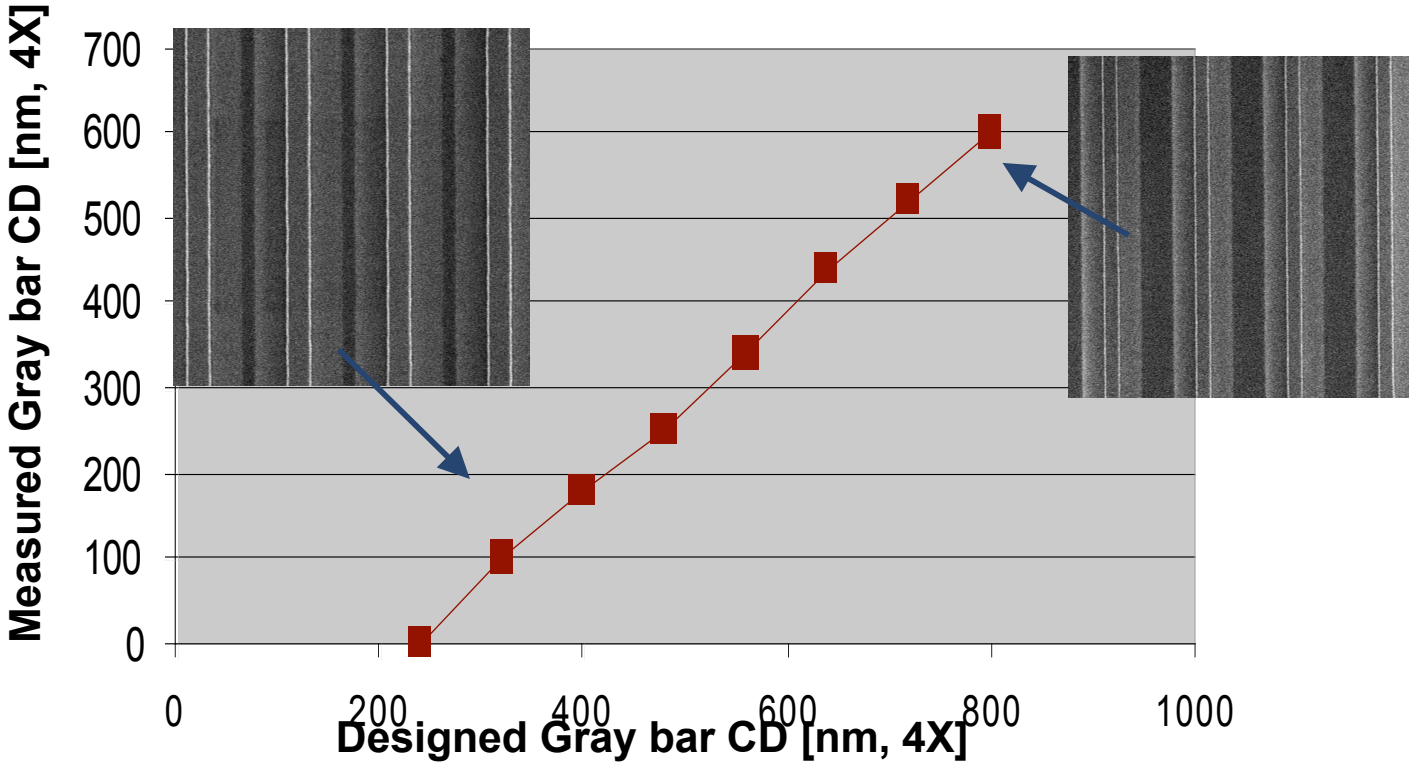


The Reticle – CD metrology

Cr-features were chosen to be 280nm (4x) through pitch

Graybar CDs were linear

- Smallest printed bar was 100nm (4x)



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Experimental Conditions

Exposures

- ASML PAS5500/1100 ArF 193nm Scanner
- 0.75NA, 0.89σ_o/0.65σ_i Quasar™ illumination
- Exposed modules: 280nm (4X) Cr CD
- 150nm Sumitomo PAR817 on 77nm Brewer Science ARC©29A

Metrology

- Litho target: 70nm
- KLA 8250XR (for wafer and reticle SEM measurements)
- KLA ProDATA 1.4.1
- KLA PROLITH 8.0.3

Impact on Diffraction Orders

Diffraction orders of a binary 1-D grating:

$$|Mag.|_{0^{th}\ order} = \left(\frac{s}{p}\right)$$

$$|Mag.|_{1^{st}\ order} = \left|\left(\frac{s}{p}\right)\sin c\left(\frac{s}{p}\right)\right|$$

$$|Mag.|_{2^{nd}\ order} = \left|\left(\frac{s}{p}\right)\sin c\left(\frac{2s}{p}\right)\right|$$

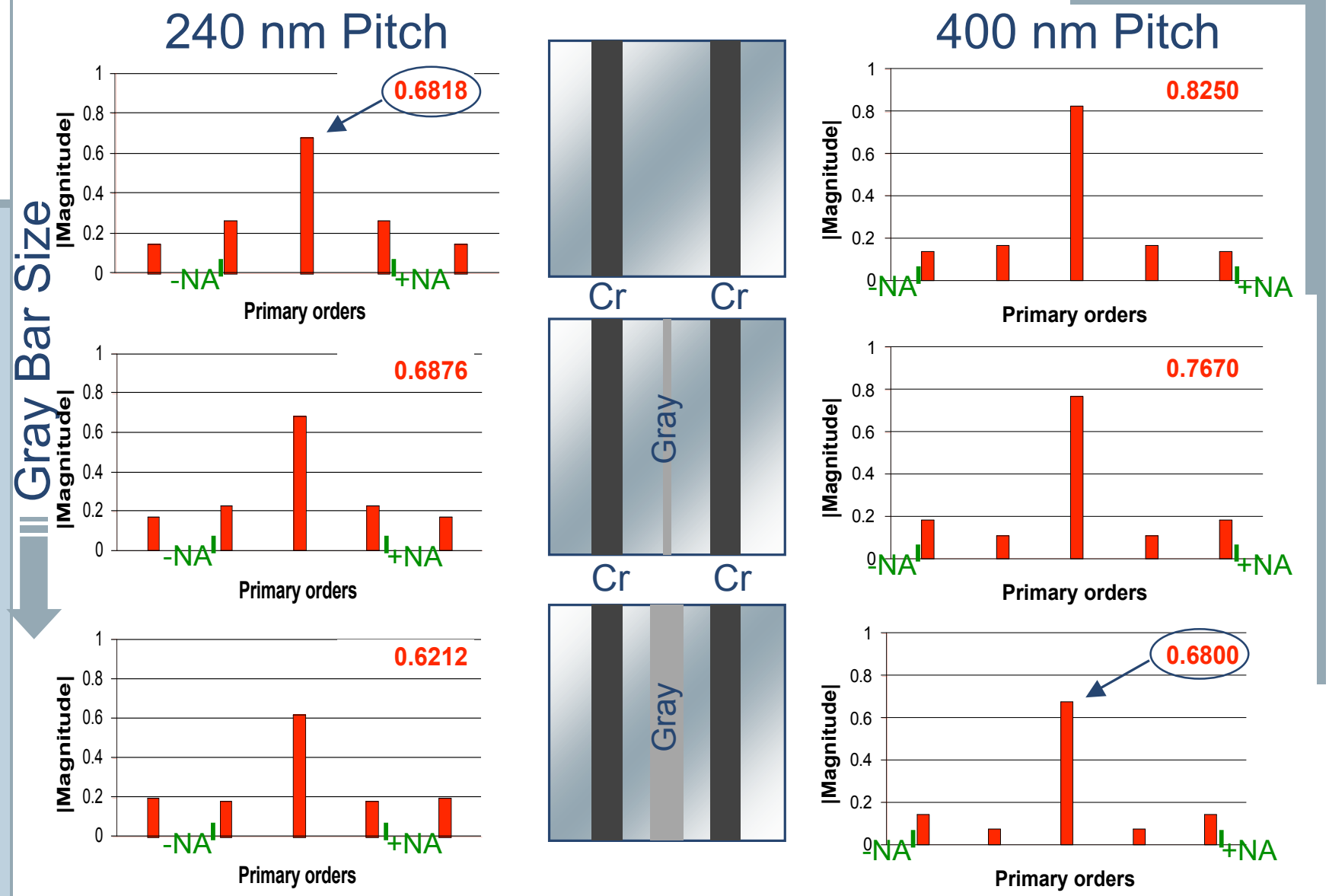
Diffraction orders of a 1-D grating with frequency-preserving gray assist bars:

$$|Mag.|_{0^{th}\ order} = \left[1-\left(\frac{b}{s}\right)\left(1-\sqrt{I_b}\right)\right]\cdot\left(\frac{s}{p}\right)$$

$$|Mag.|_{1^{st}\ order} = \left|\left(\frac{s}{p}\right)\sin c\left(\frac{s}{p}\right)-\left(1-\sqrt{I_b}\right)\left(\frac{b}{p}\right)\sin c\left(\frac{b}{p}\right)\right|$$

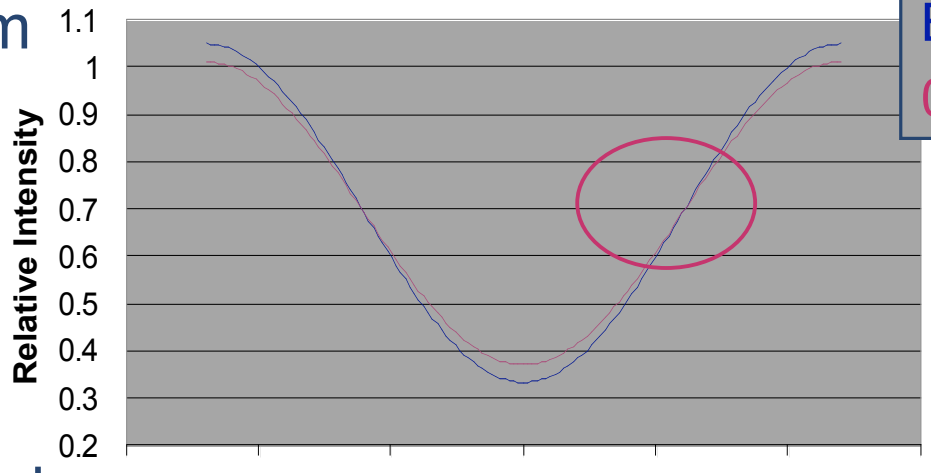
$$|Mag.|_{2^{nd}\ order} = \left|\left(\frac{s}{p}\right)\sin c\left(\frac{2s}{p}\right)-\left(1-\sqrt{I_b}\right)\left(\frac{b}{p}\right)\sin c\left(\frac{2b}{p}\right)\right|$$

Diffraction Information



Aerial Image Slices

240 nm

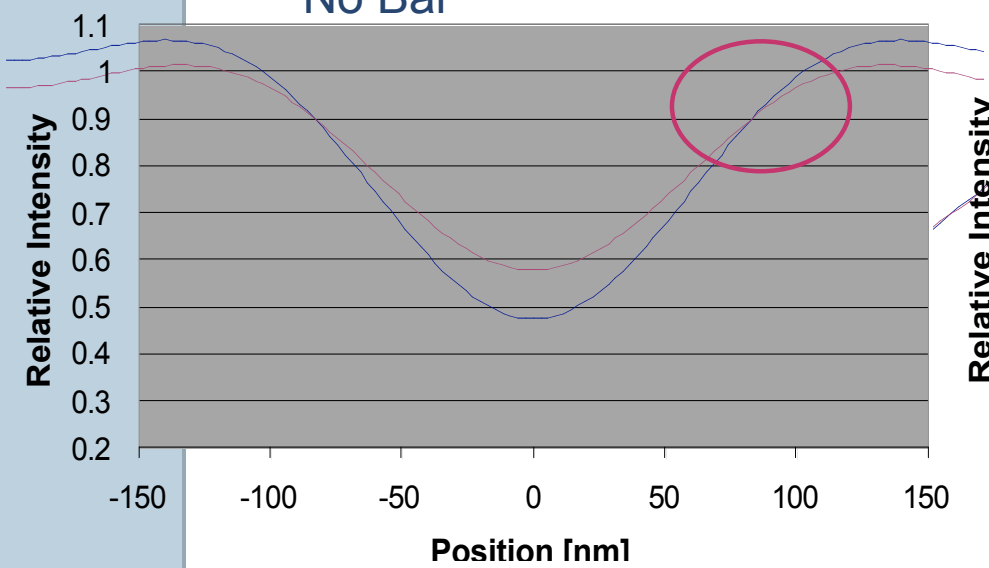


Best focus

0.2µm defocus

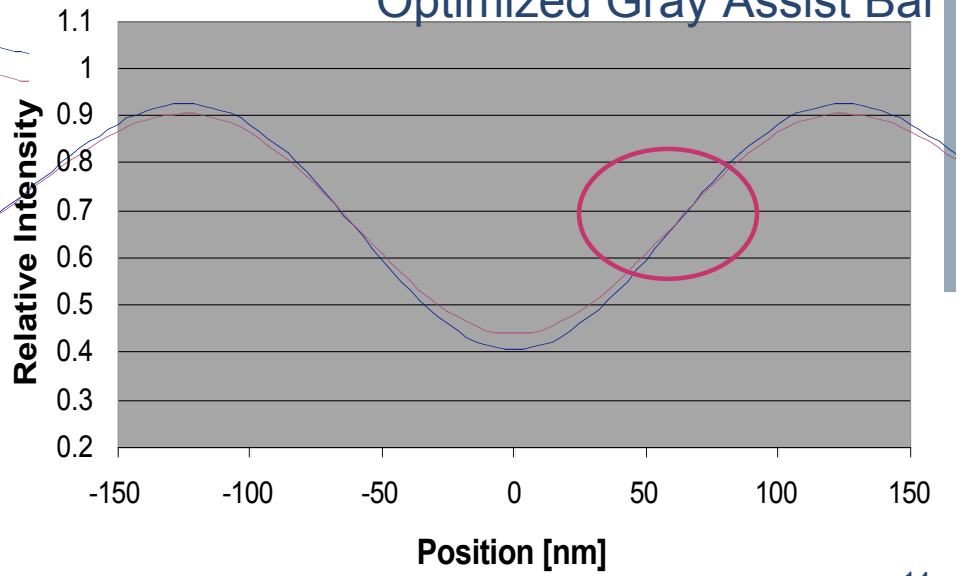
500nm Pitch

No Bar



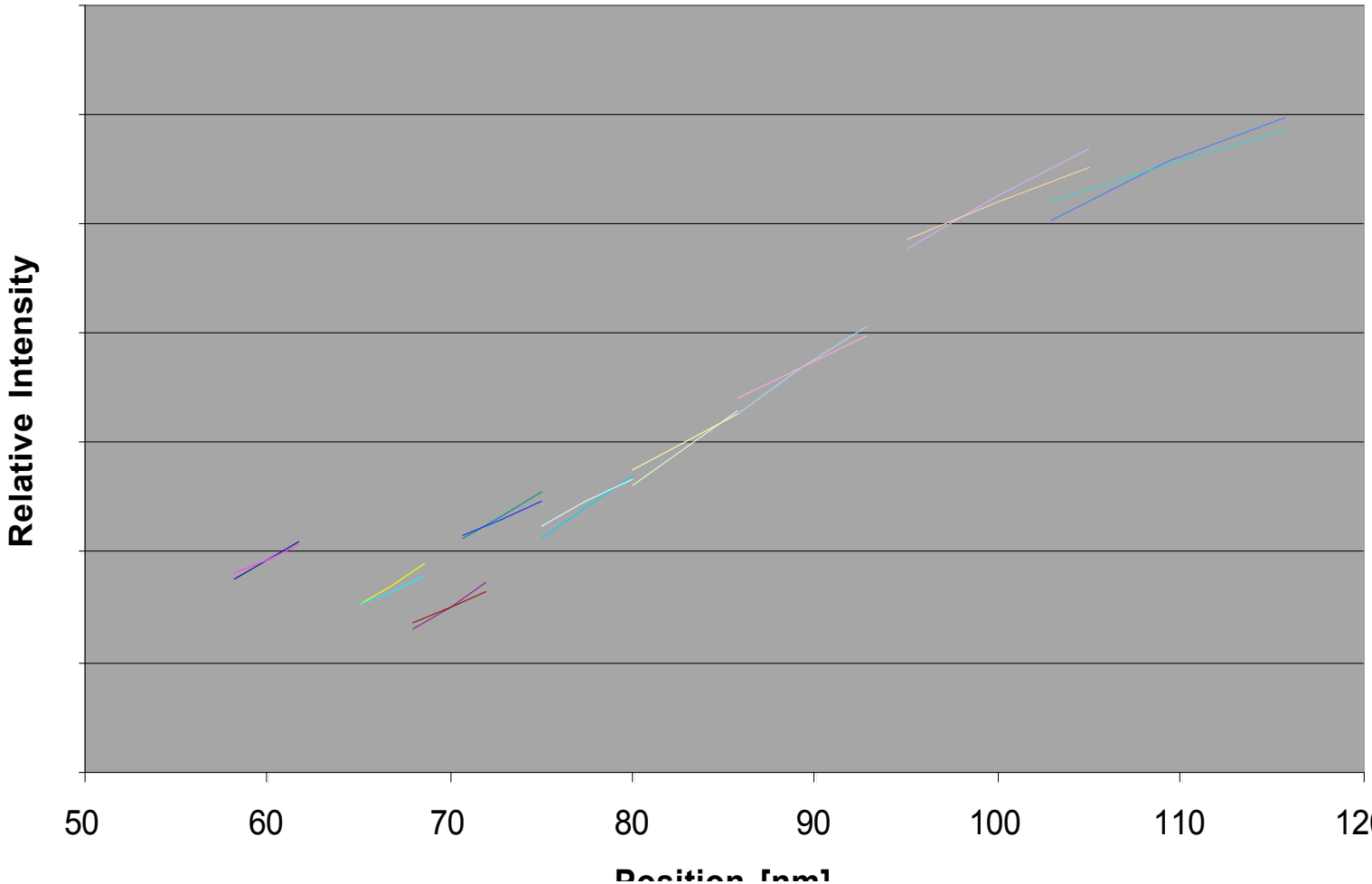
500nm Pitch

Optimized Gray Assist Bar



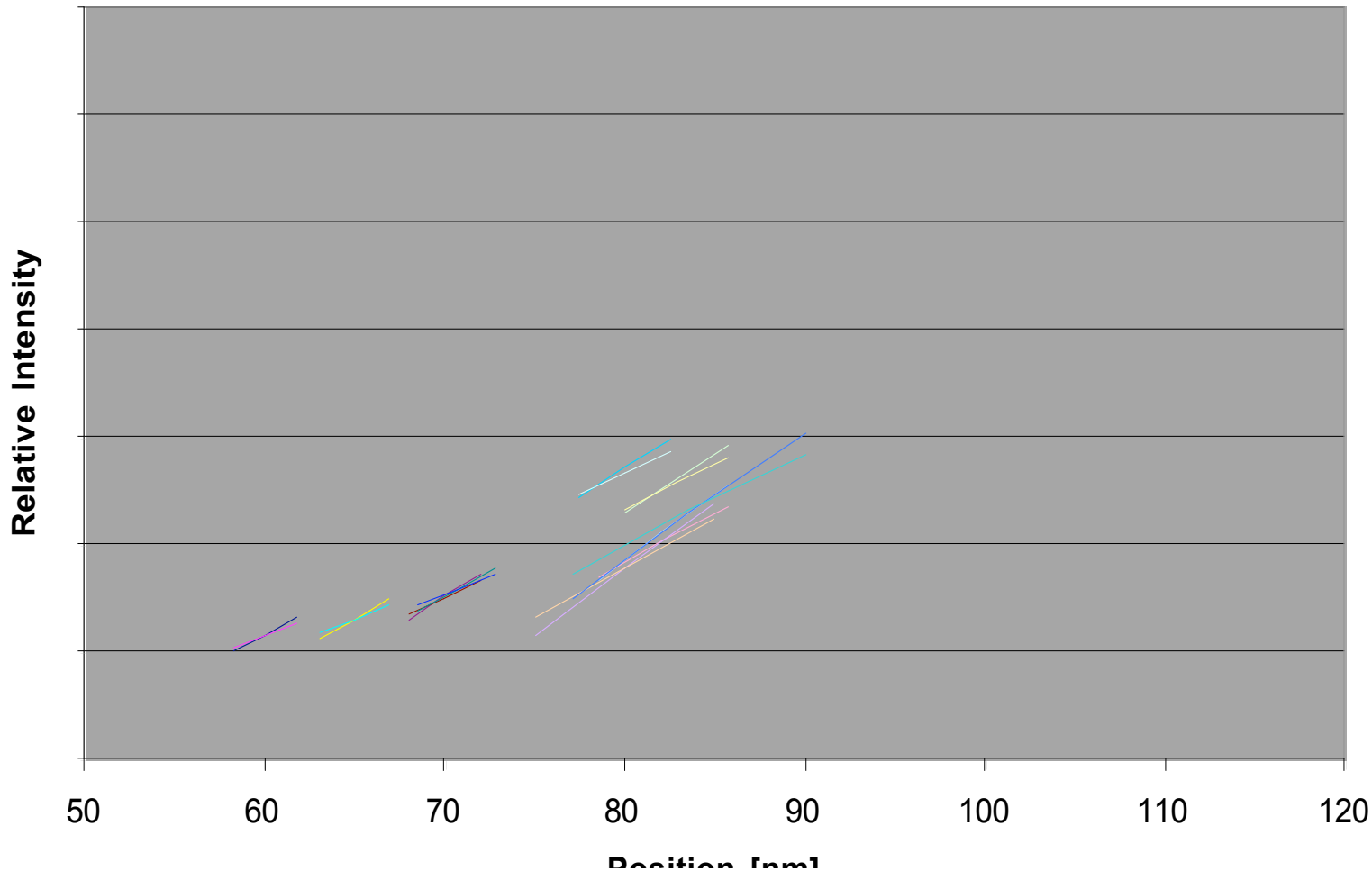
Isofocal Slices Through Pitch

No Gray Assist Bars



Isofocal Slices Through Pitch

With Gray Assist Bars and Cr Bias



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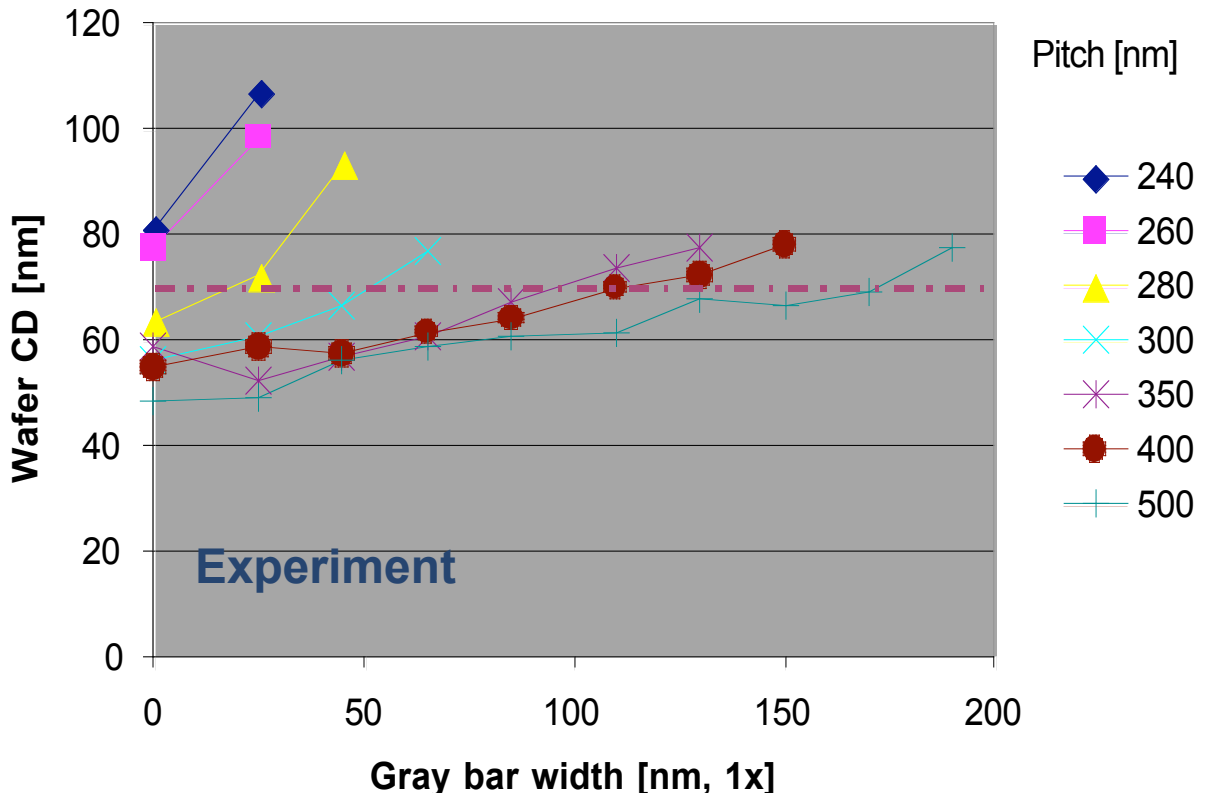
Proximity Matching

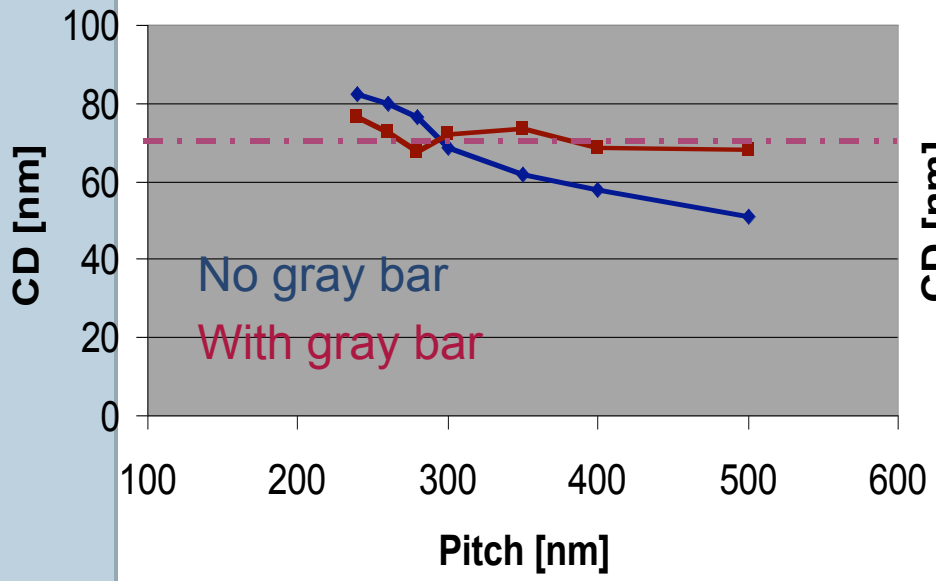
CD tuning with gray bars

- At a given dose and focus, addition of gray assist bars can be used to select cases through pitch with the same CD

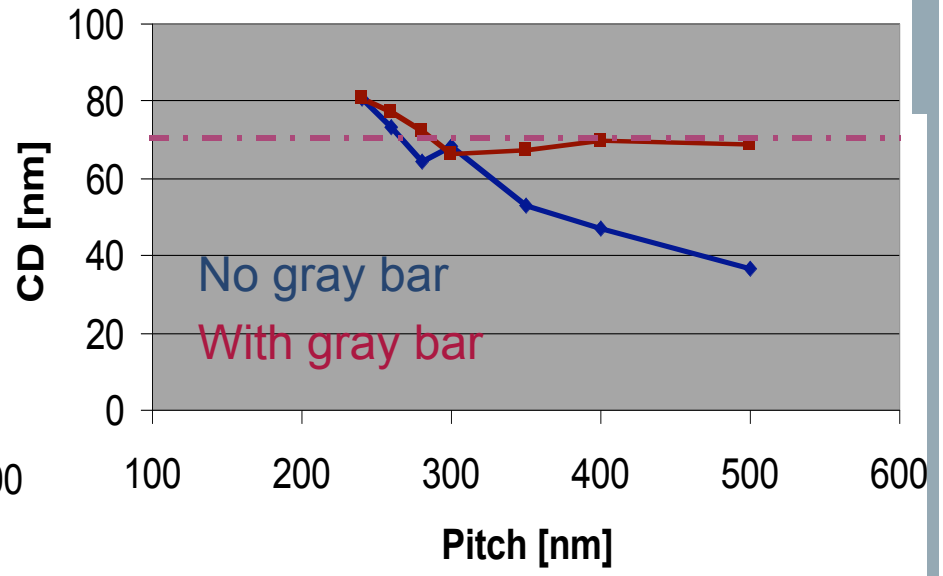


Proximity matching

Simulation



Experiment



By adding gray assist bars, proximity effect can be corrected.

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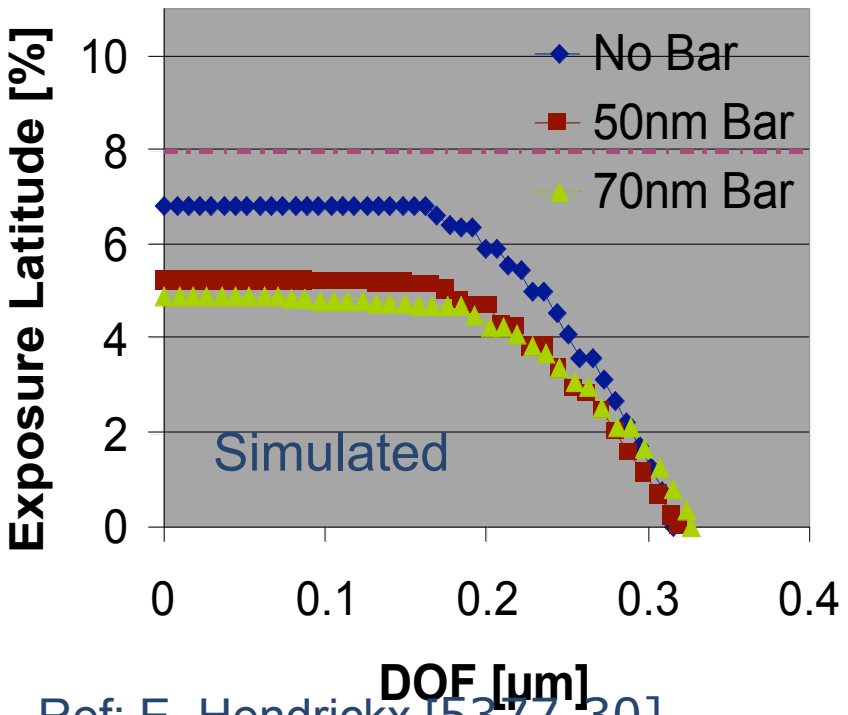
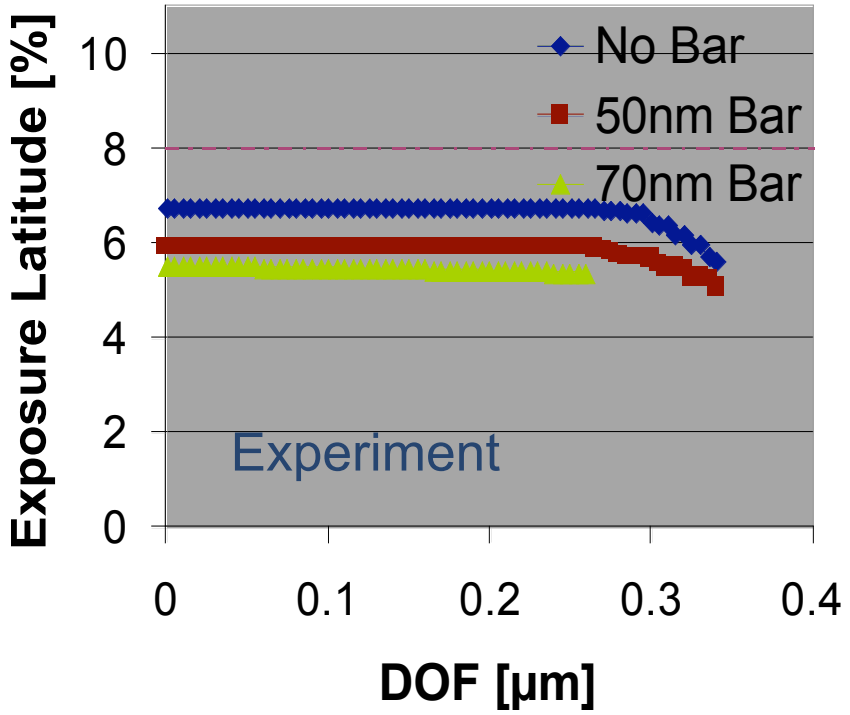
DOF and PW with Gray Bars

Before and at Forbidden Pitch:

- 2nd order lies outside of pupil
- Graybar reduces 1st and 0th order and hence the image contrast



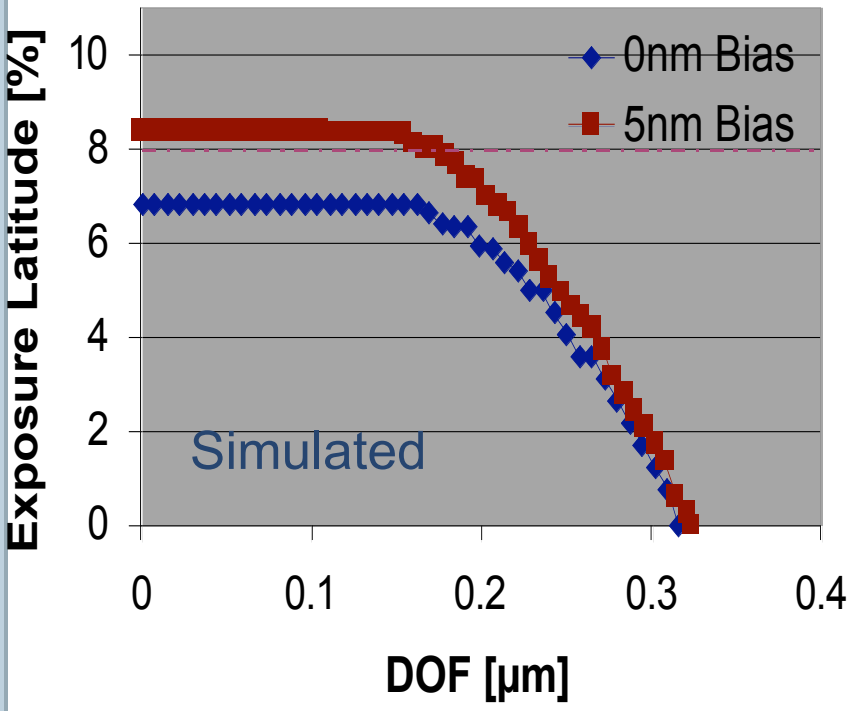


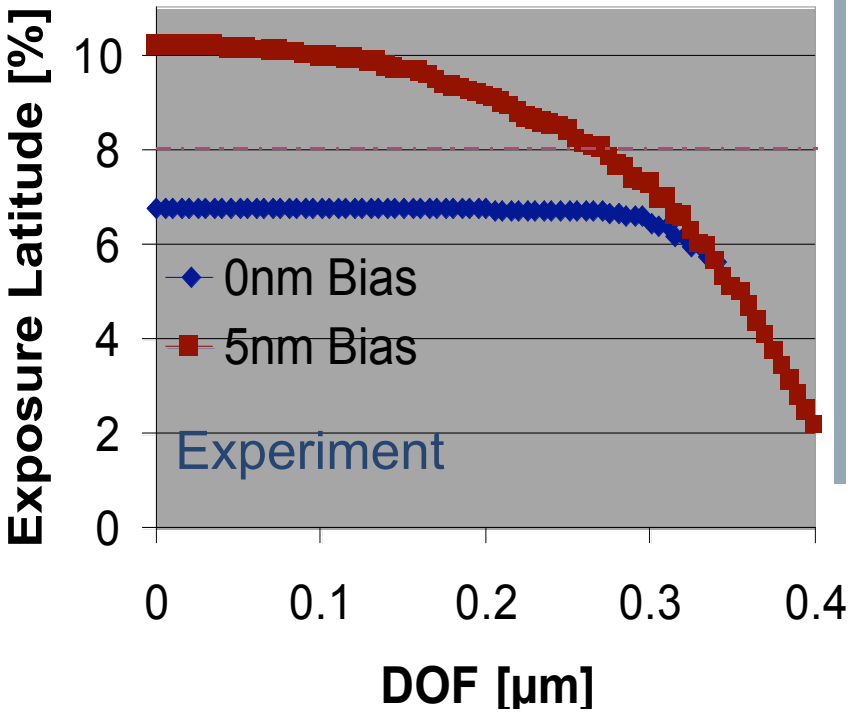
Ref: E. Hendrickx [5377-30]

DOF and PW with Gray Bars

Solution:

- Cr bias before/at forbidden pitch to match 0th order
- Small increase in +/- 1st order
- 0th order decrease

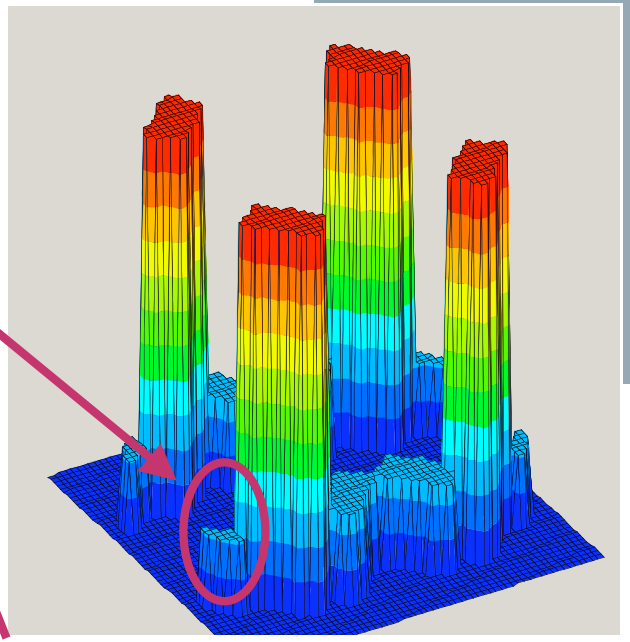




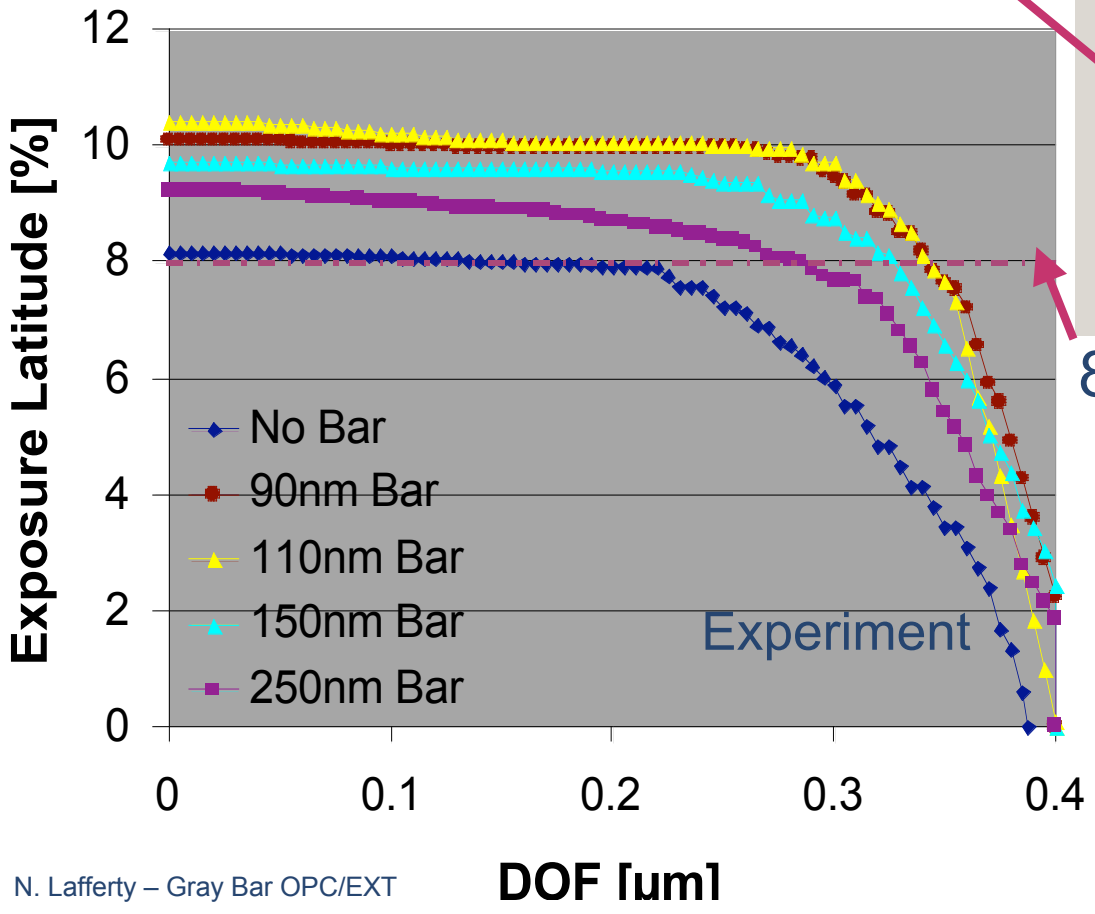
DOF and PW with Gray Bars

At pitches > forbidden pitch:

- 2nd order begins to enter pupil



8% EL



500nm Pitch
70nm CD

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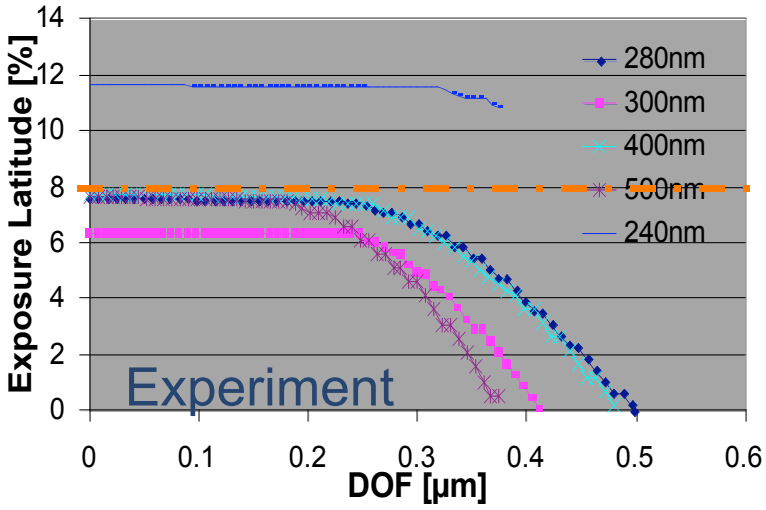
Individual Process Window Increase

Without Gray Bar

Unassisted Cr

Larger Pitches < 8%EL

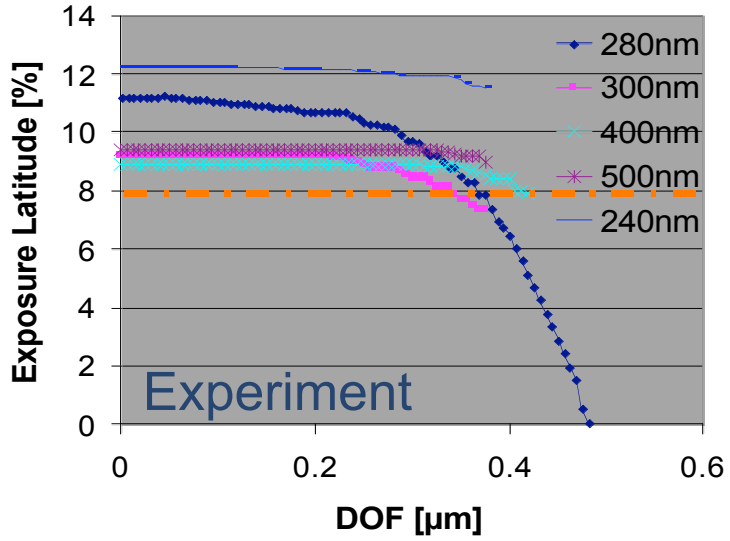
- Not Acceptable



With Gray Bar

Optimized Assist Features

Significant EL gain



Overlapping Process Window Increase

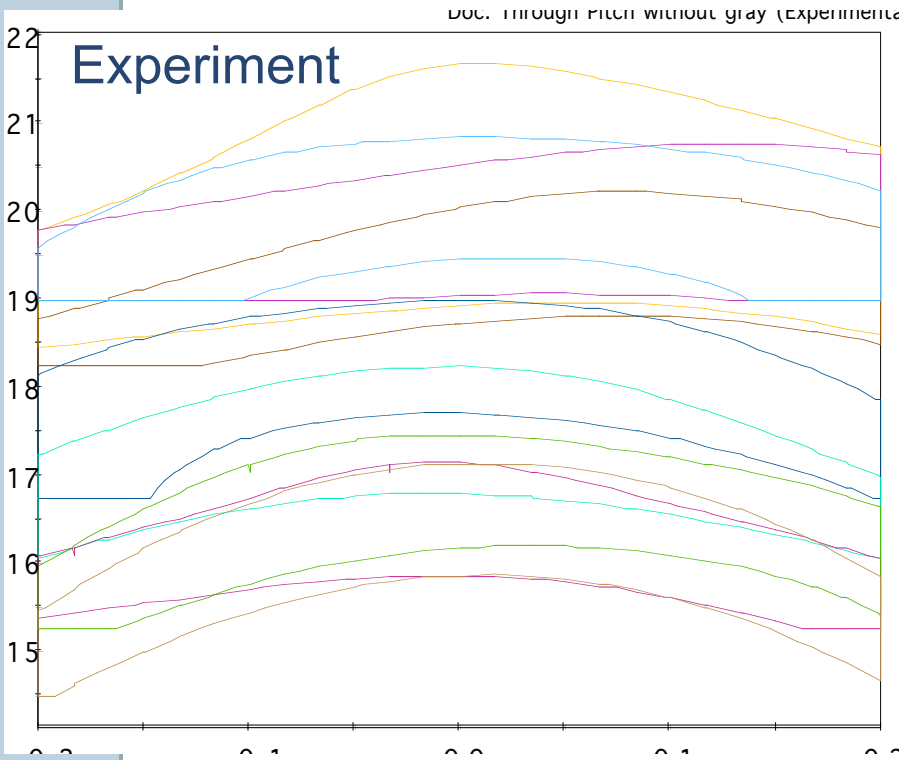
No Assist Features

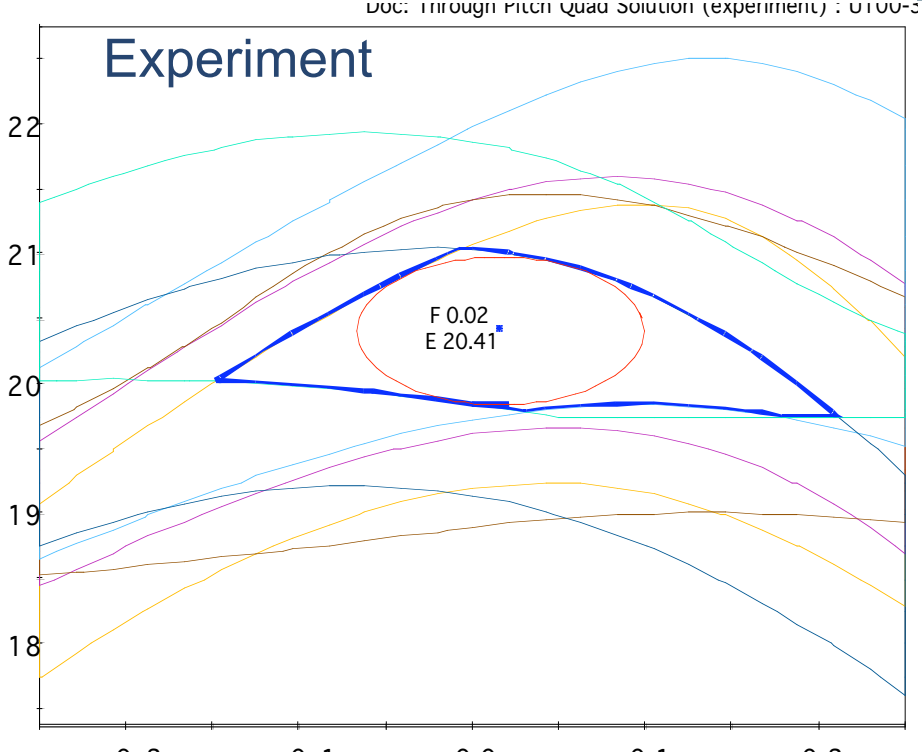
No overlapping Process Window

With Gray Assist Features

5.6% Exposure Latitude

0.17µm DOF





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We have experimentally proven that Gray Assist Bar OPC can:

- Reduce 0^{th} order diffraction information, while adding 2^{nd} order information
- Improve NILS of assisted vs. unassisted cases
- Be a viable approach for reducing proximity effects
- Increase usable DOF and exposure latitude for features spaced > forbidden pitch
- Tune individual process windows for maximum overlap through pitch

In Addition:

- The graybar mask was manufactured successfully with good control of the gray bars.
- The reticle is an excellent step forward in assist feature OPC

Acknowledgements

Stephen Hsu

- Creating GDS file

Eric Hendrickx

- Discussions on forbidden pitch treatment and illumination effects

Patrick Willems

- Exposures/Measurements

This work is in follow-up to a previous SPIE 2001 paper *'Mutually Optimizing Resolution Enhancement Techniques: Illumination, APSM, Assist Feature OPC and Gray Bars'*, Dr. Bruce W. Smith *[4348-48]*

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