EUV Interference Lithography

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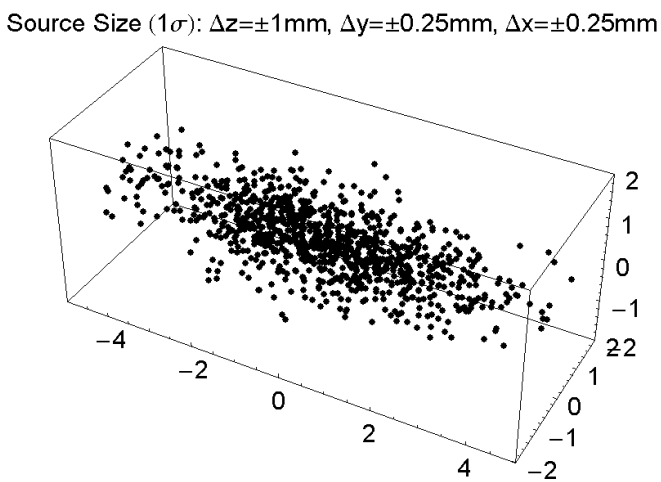

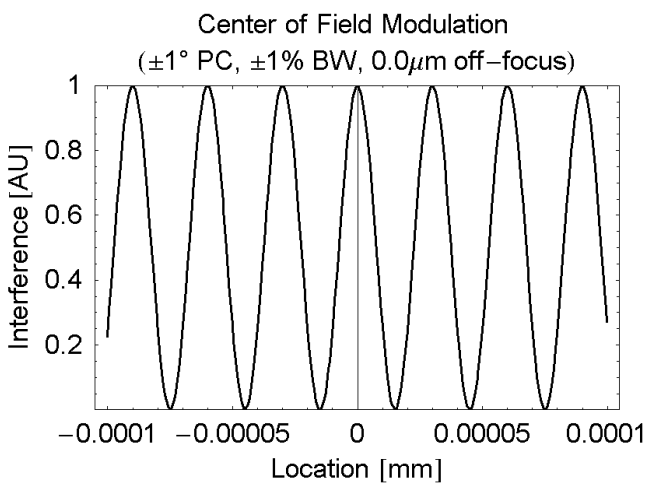

φ = Intel Corporation (www.intel.com), λ = Optica Software (www.opticasoftware.com)

Outline

- **Abstract**
- **Modeling Approach**
- **Optical Designs Considered**
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  - Single grating
  - Single grating with two plane mirrors
  - Double (cascaded) gratings
  - Imaging systems (1X Offner and 10X Schwarszchild)
- **Performance Comparison**
- **Radiometric Tradeoffs**
- **Conclusions**

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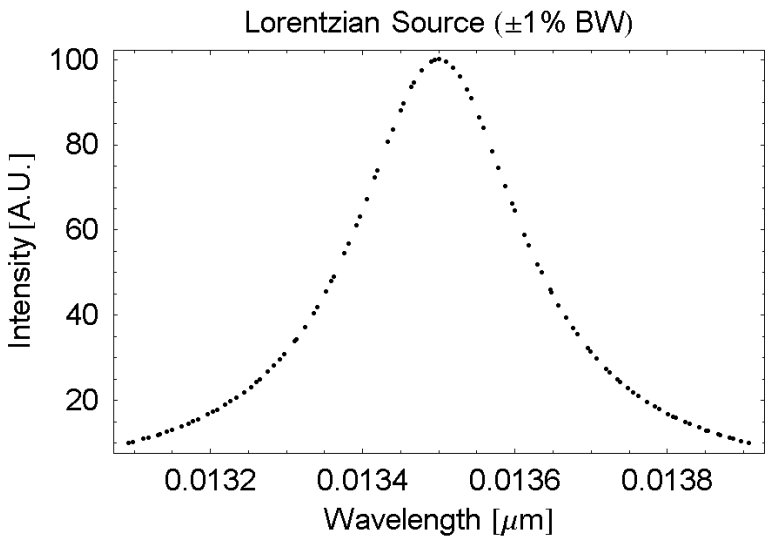
Abstract

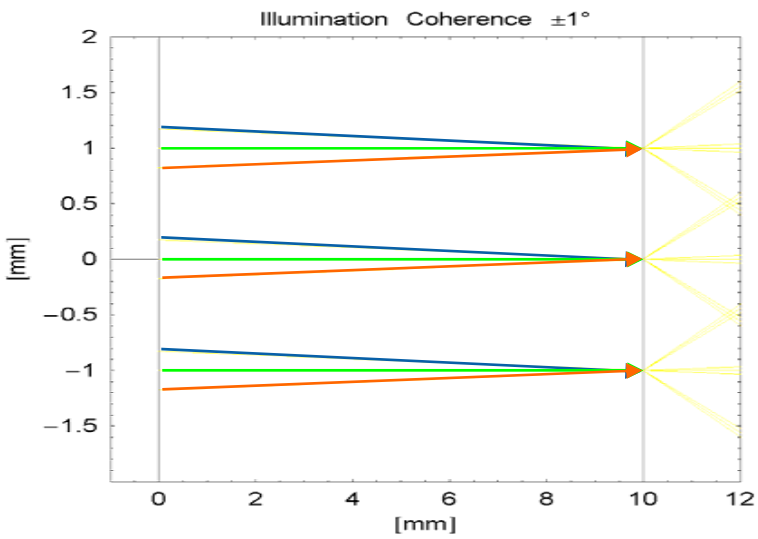
Photoresist performance is one of the highest risks impeding the adoption of extreme ultra-violet (EUV) lithography. A critical issue in addressing this challenge is the lack of a practical and affordable optical system for evaluating new materials at resist suppliers. The objective of this work is to compare the performance and economics of optical designs for EUV interference lithography (EUV-IL). Although synchrotron based EUV-IL systems do exist, our study will address the issues associated with using a relatively incoherent plasma source.

The key parameters in the optical evaluation are source coherence requirements, contrast, depth of focus, field size, and radiometric efficiency. Economic factors include system complexity and cost, platform issues, and cost of ownership. Five systems were explored for this study that employed a single grating, cascaded gratings, a grating with two mirrors, and grating imaging systems with 1X Offner and 10X Schwarzchild optics. Considering source constraints, system performance and economics, the cascaded grating model has advantages for this particular application.

Modeling Approach

- Ray tracing methods employed to calculate optical path length (phase) for coherent and incoherent plane waves.
- Wavefronts were traced with multiple rays through the optical systems. Vector addition of the complex fields was employed for coherent waves, and intensities were added for incoherent waves at the wafer plane.
- Lorentzian spectral function used to model bandwidth.
- Tilted and design perturbed wavefronts both lead to spatial incoherence.





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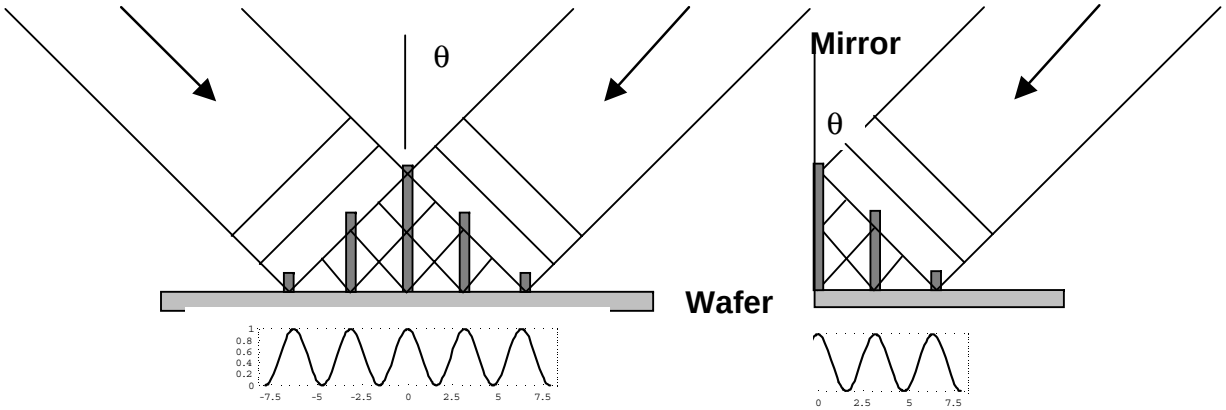
Folded / Split Wavefronts

- **Interference can be generated with either folded or split wavefronts.**
- **Young's configuration is commonly used and will be considered here.**
- **Lloyd's mirror is a typical configuration with a folded wavefront.**
  - Necessitates a different optical path length for interfering waves. A short temporal coherence length limits field size.
  - Mirror contamination may occur from photoresist out gassing.



Young's Configuration **Lloyd's Mirror**

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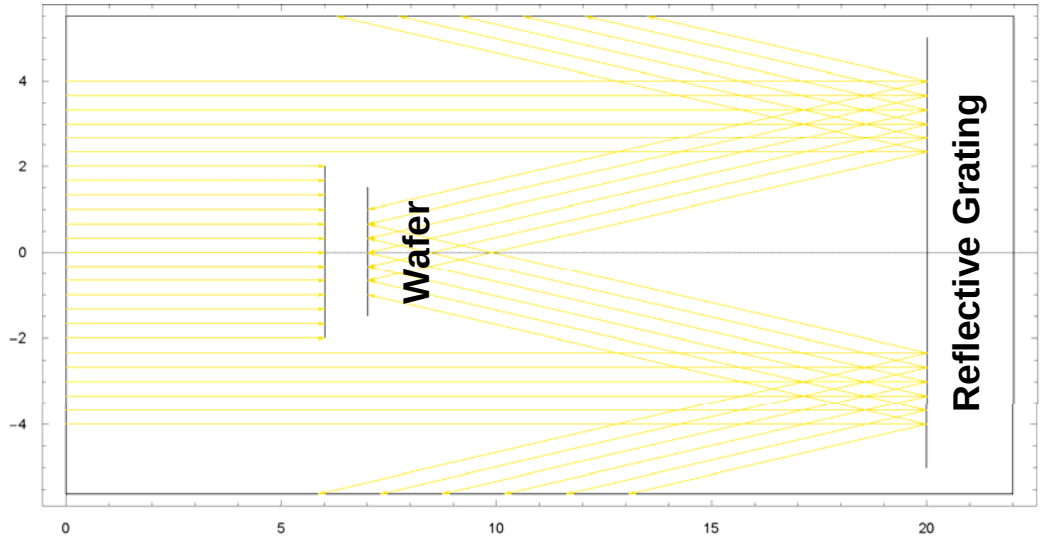
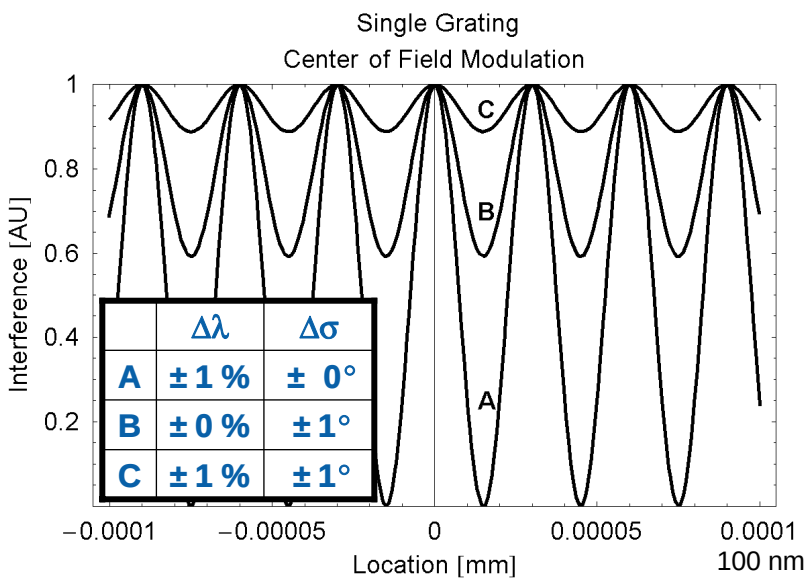
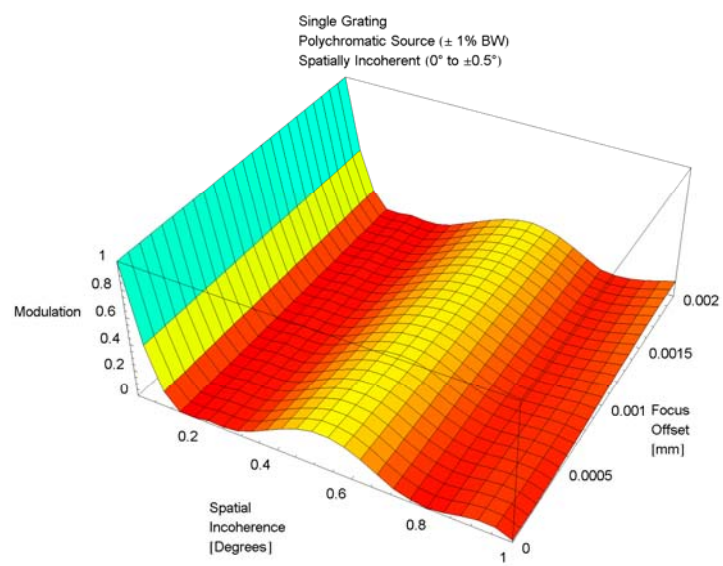
Single Grating Model, 15 nm L/S



- **Advantages**
  - No mirrors (flare, $)
  - Easy alignment
  - Reflective grating
- **Disadvantages**
  - Spatial incoherence sensitivity
  - Pitch/focus dependence



	Δλ	Δσ
A	±1%	± 0°
B	±0%	±1°
C	±1%	±1°



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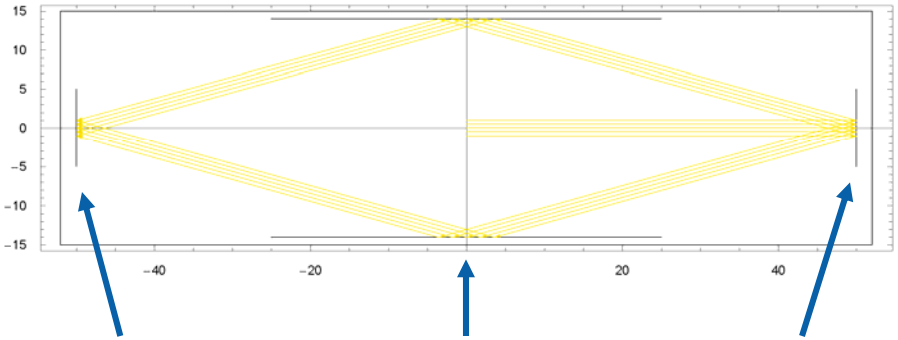
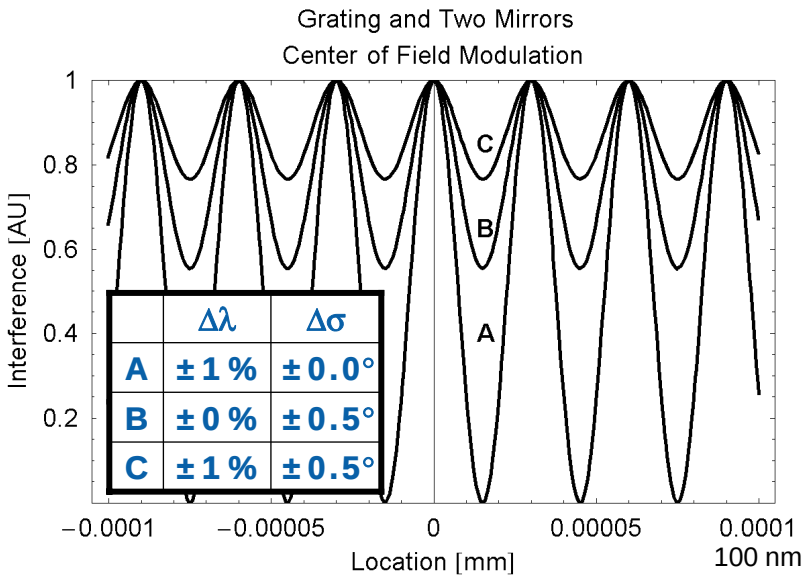
Single Grating with Two Mirrors

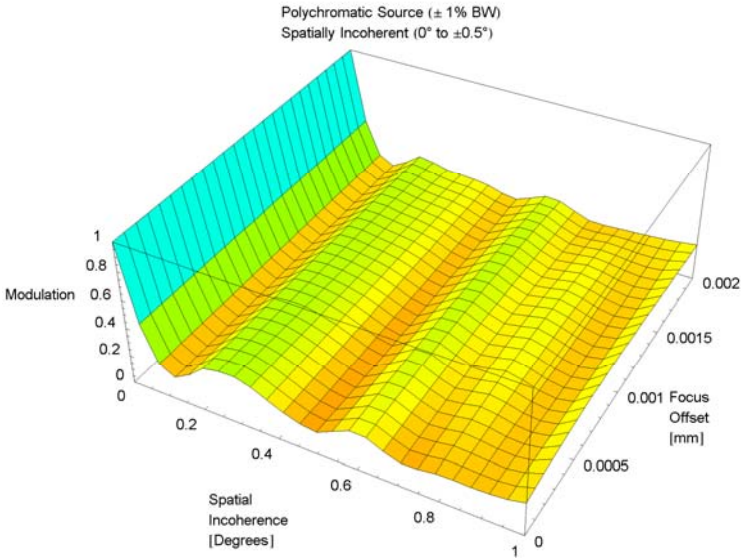


Wafer **Mirrors** **Reflective Grating**

- **Advantages**
  - Simple optics (flare, $)
  - Reflective grating
  - Minimal alignment sensitivity
- **Disadvantages**
  - Spatial incoherence sensitivity
  - Pitch/focus dependence



	Δλ	Δσ
A	±1%	±0.0°
B	±0%	±0.5°
C	±1%	±0.5°



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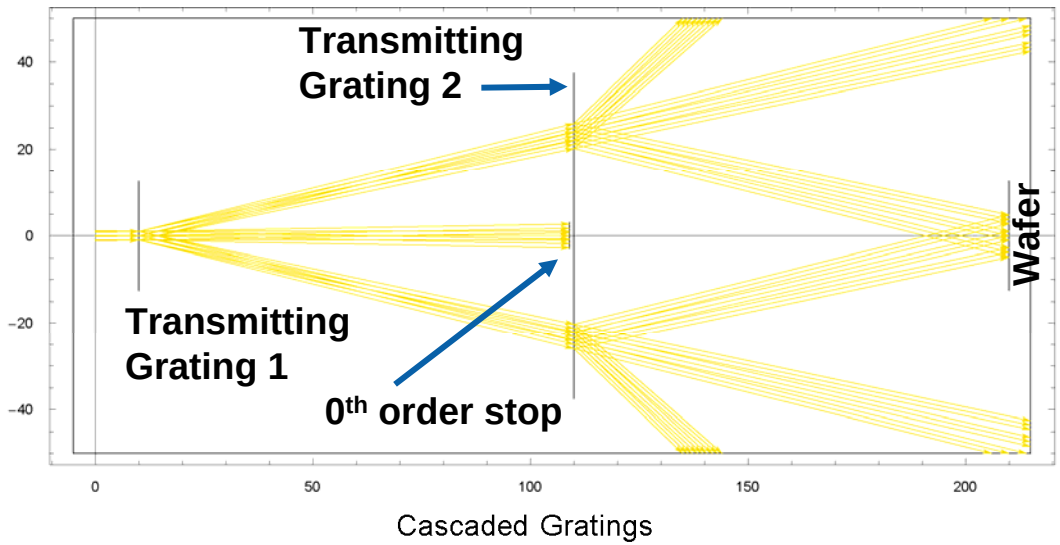
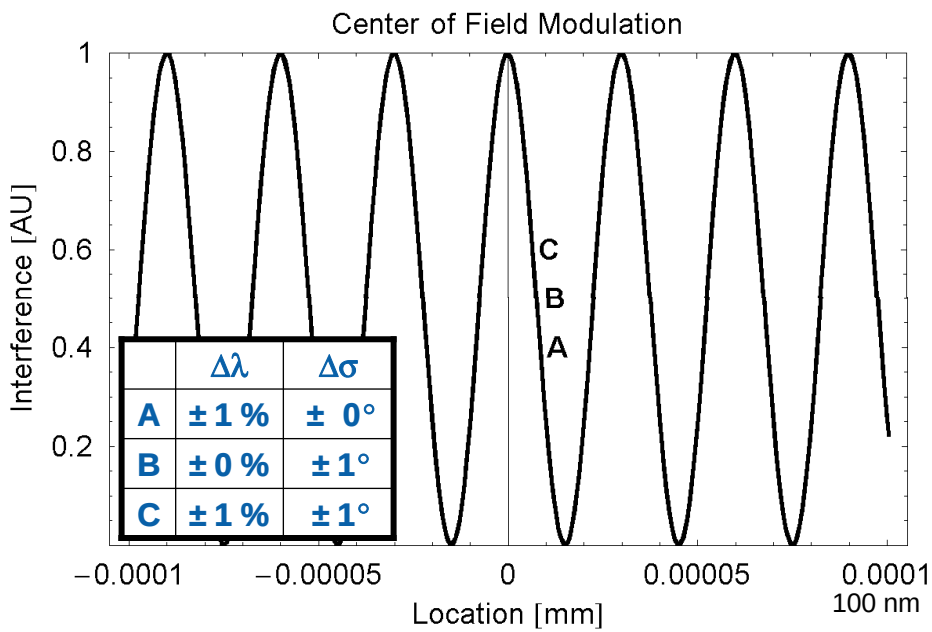
Double (Cascaded) Grating Model



- **Advantages**
  - No Mirrors (flare)
  - Achromatic
  - Spatial coherence
  - Multi-pitch printing
- **Disadvantages**
  - Transmitting gratings
  - Field size / min pitch interaction



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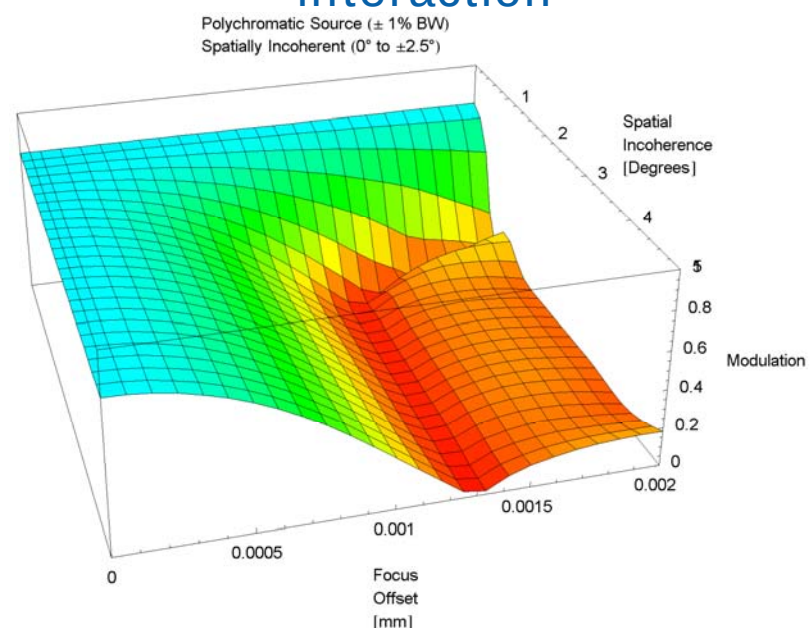
B	±0 %	±1°
C	±1 %	±1°



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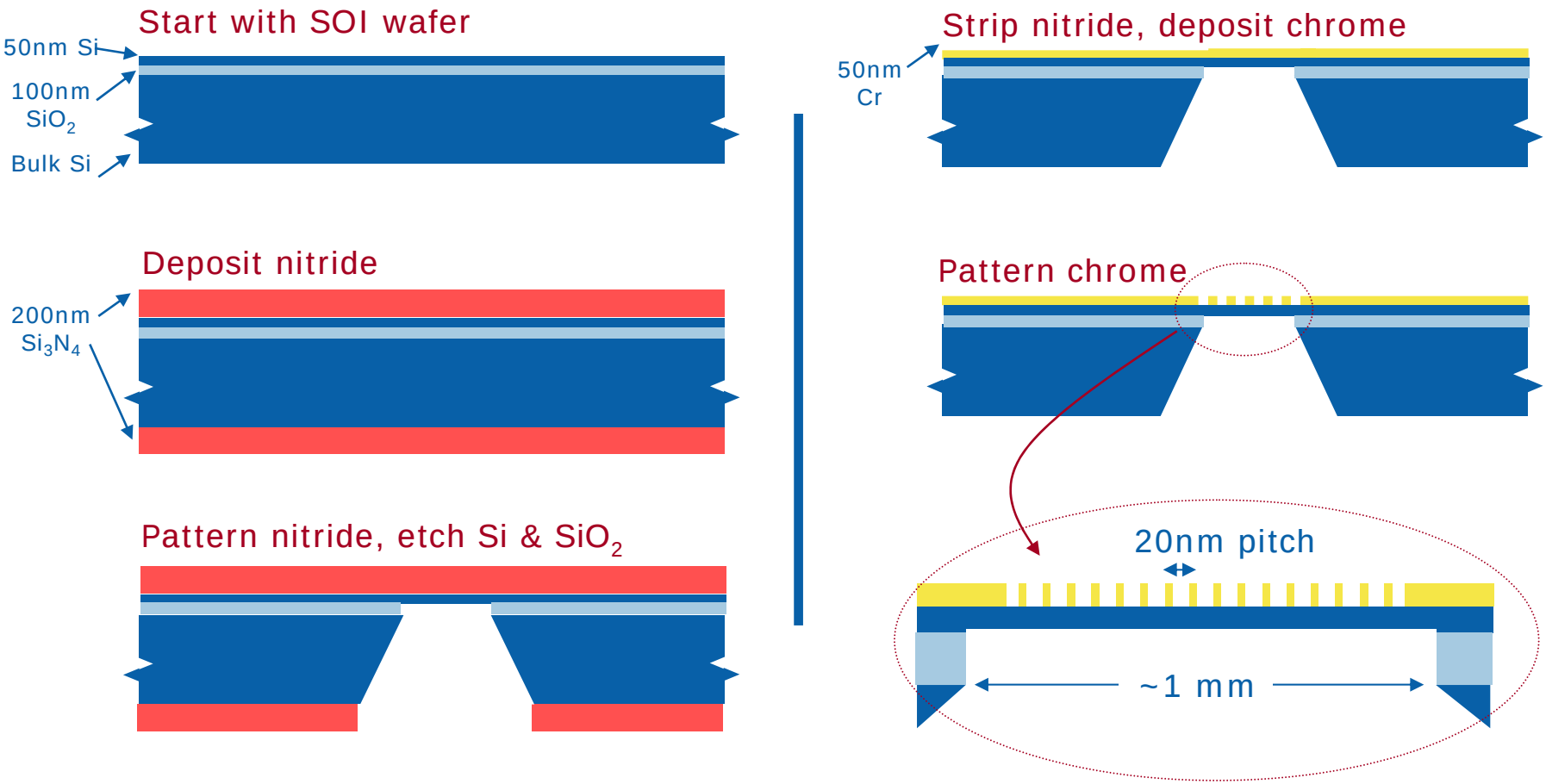
Transmitting Grating Fabrication



Comment: This process flow was created at Intel (Y.A. Shroff). Other techniques for fabricating diffractive optics have been demonstrated at CXRO. Completely free-standing gratings have been described elsewhere. Nonetheless, obtaining small pitch gratings of high quality is expected to be one of the significant challenges for EUV-IL.

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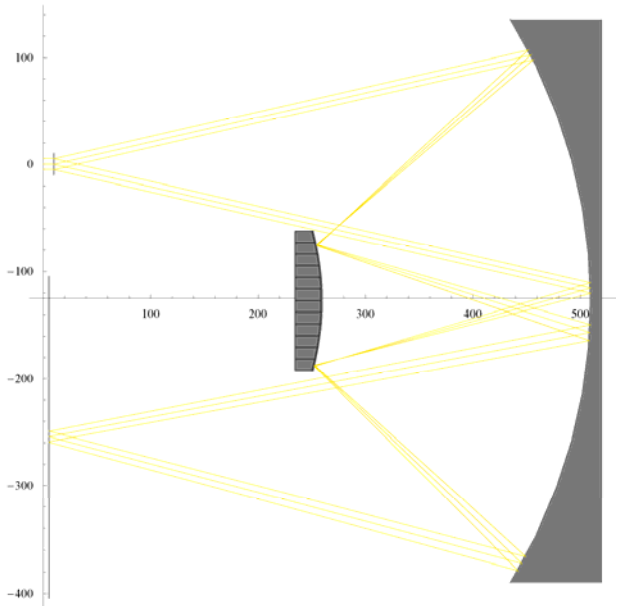
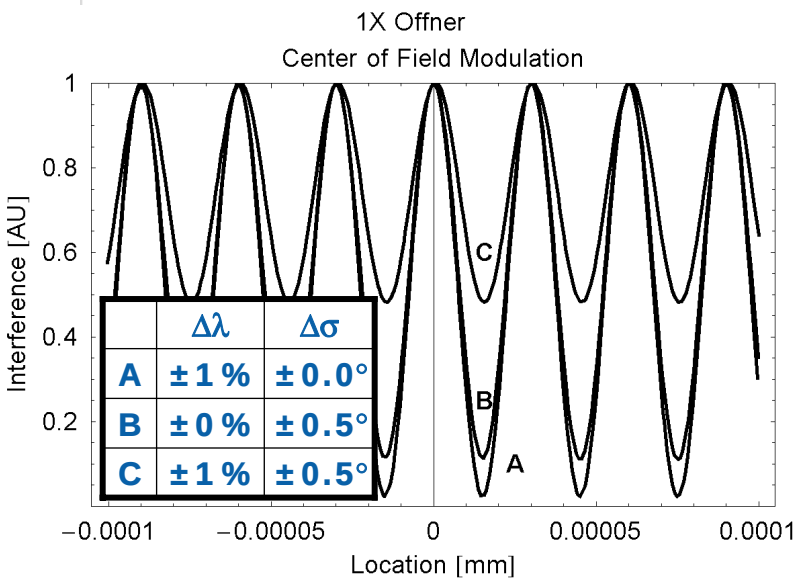
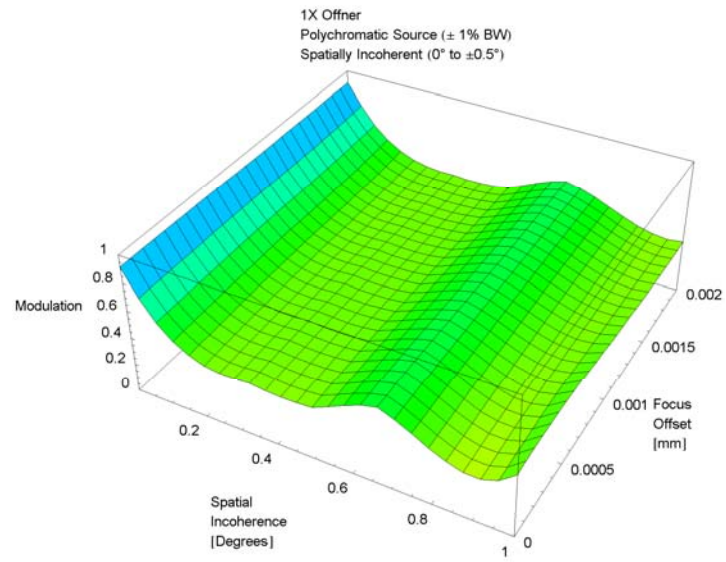
1X Offner Imaging Model



- **Advantages**
  - Spherical mirrors
  - Low distortion
- **Disadvantages**
  - Cost of large optics
  - Flare generated speckle
  - Alignment sensitivity
  - Etendue spatial coherence limit



	Δλ	Δσ
A	±1%	±0.0°
B	±0%	±0.5°
C	±1%	±0.5°



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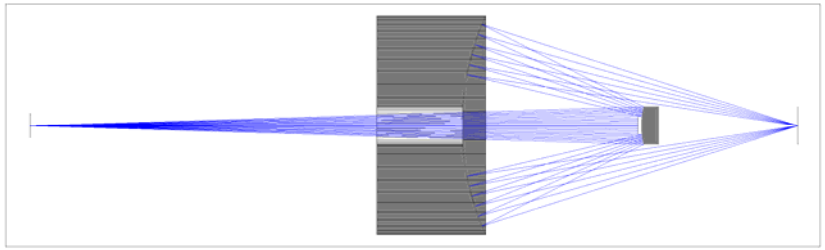
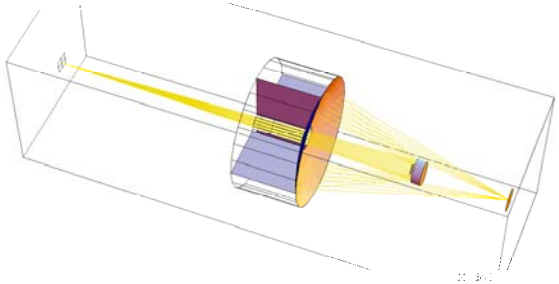
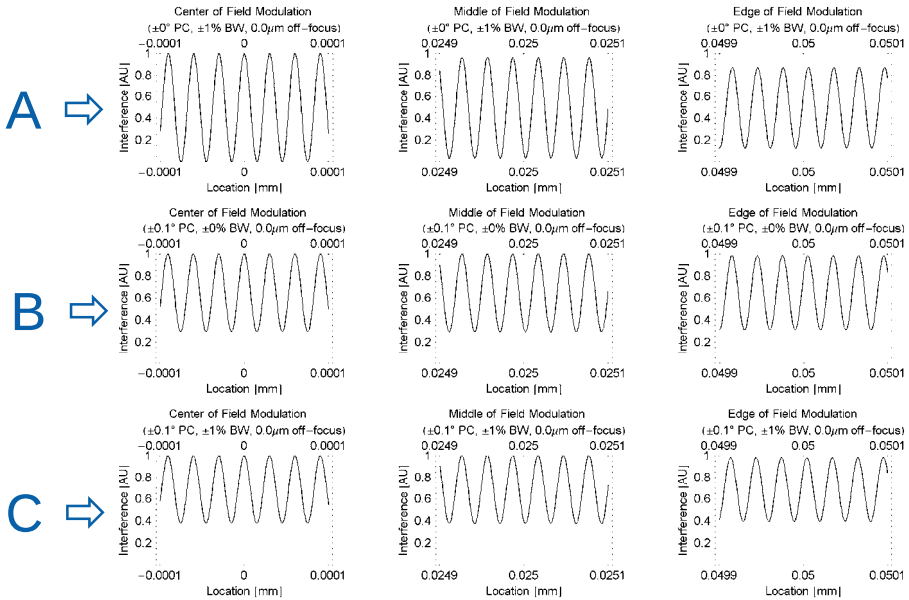
10X Schwarzschild Imaging Model

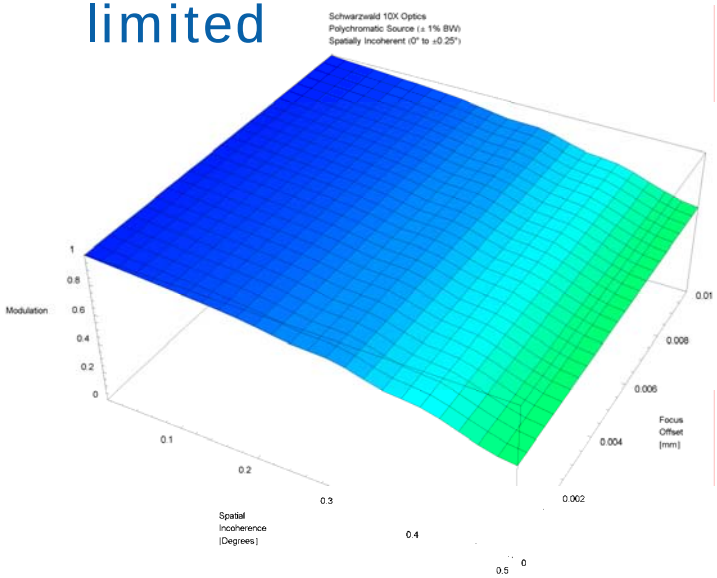




	Δλ	Δσ
A	±1%	±0.0°
B	±0%	±0.1°
C	±1%	±0.1°

- **Advantages**
  - Spherical mirrors demonstrated
- **Disadvantages**
  - Small field size
  - Flare generated speckle
  - Alignment sensitivity
  - Etendue spatial coherence limited





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Design Comparison for ±1% BW

Design	Field Size	DOF (for modulation = 0.6)	Spatial Coherence with ±1% BW
Single Grating	Illuminator limited	Microns	0.05 degrees
Two Mirror Grating	Illuminator limited	Microns	0.05 degrees
Cascaded Grating	Grating and illuminator limited	0.8 μm ⇨ 2 μm	5 ⇨ 2 degrees
1X Offner Imaging	TBD	Microns	1 degrees
10X Schwarzschild Imaging	100um	Microns	0.5 degrees

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Radiometric Comparison

- A highly simplistic approximation of transmission is calculated here from the spatial coherence limited solid angle, grating efficiency, and mirror reflectivity.
- Illumination approach is expected to further differentiate transmission of the systems.
- The optimal system based on exposure time is very different for spatially coherent and partially coherent sources.

Input Variables		***Units***				**User Defined**
Required Dose	10	mJ/cm^2				Output
Field Size	1	mm^2	=	0.01	cm^2	
Plasma Source Power in 2 Pi	10	W=J/s	=	10000	mJ/s	
Using a Coherent Source…	0.1	W=J/s	=	100	mJ/s	
Deffraction Efficiency	7%	%				

Visit http://www-cxro.lbl.gov for grating efficiency calculations.

	Cascaded Grating	**Single Grating**	**Two Mirror Grating**	**1X Offner**	**10X Schwarzschild**
Grating Efficiency (x0.65 for reflective)	7.00%	4.55%	4.55%	4.55%	4.55%
Mirror Reflectivity	N/A	N/A	0.65	0.65	0.65
Apodization	N/A	66.70%	N/A	N/A	N/A
System Transmission	**0.49%**	**3.03%**	**2.96%**	**1.25%**	**1.92%**
System with a coherent source					
Power at Wafer Plane (mJ/s)	0.49	3.03	2.96	1.25	1.92
Exposure Time (s)	0.20	0.03	0.03	0.08	0.05
System with a plasma source					
Acceptable Spatial Incoherence (for 60% modulation)	5	0.05	0.05	1	0.5
Solid Angle (str)	0.023909417	2.39246E-06	2.39246E-06	0.00095696	0.000239244
Collection Efficiency	0.38%	0.00%	0.00%	0.02%	0.00%
SPF Efficiency	50%	50%	50%	50%	50%
Power at Wafer Plane (mJ/s)	0.093230	0.000058	0.000056	0.009516	0.003660
Exposure Time (s)	**1.07**	**1730.72**	**1775.99**	**10.51**	**27.32**

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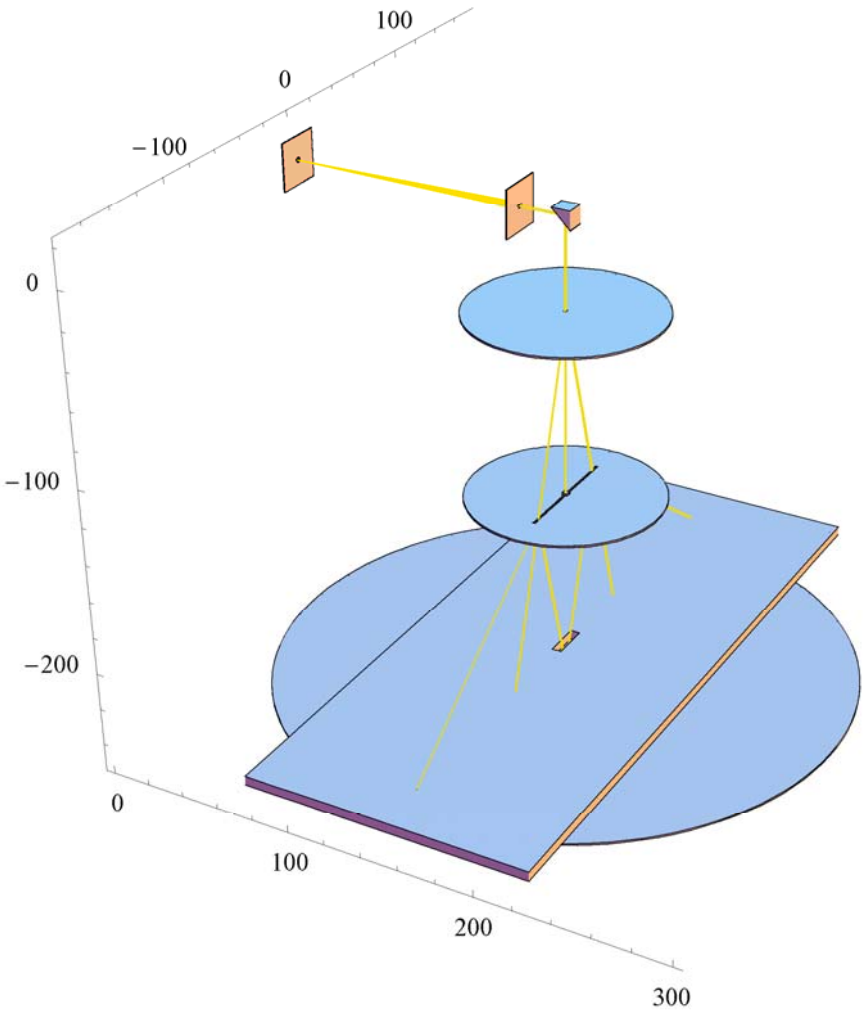
Cascaded Grating System Components



- **System Components**
  - Collection optics
  - Spatial filter
  - Field framing baffle (w/ dose detectors)
  - Condenser mirror (off-axis parabolic)
  - First grating
  - Zero order stop
  - Second grating
  - Multi-order stop
  - Wafer

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Conclusion

- **Ray tracing is widely used for imaging system analysis. Optica Software routines that capture grating phase constraints and analyze partially coherent interference were employed for this modeling.**

- **Five EUV-IL optical designs were modeled to determine 15nm line/space performance with likely commercial sources parameters (temporally and spatially incoherent).**

- **Considering source constraints, system performance and economics, the cascaded grating system has advantages for the EUV-IL application.**
  - Simultaneous multi-pitch printing
  - Reasonable partial coherence requirements from EUV source
  - Micron depth of focus is possible, adjustable
  - Requires transmitting gratings, but no imaging mirrors

- **Detailed modeling is recommended for any selected designs to understand expected performance. A sensitivity analysis is recommended for tolerancing.**

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