Silicon Diffractive Elements by projection photolithography.”

NASA Phase 2 SBIR (**NNG07CA05C**). NASA monitor: David Content

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Outline

1. Background. Principles and advantaged of DUV photolithography for diffraction structures fabrication.
2. Constellation-X grating prototype: design and fabrication approach - flat substrate.
3. NEXUS grating prototype: design and fabrication approach - cylindrical substrate.
4. Existing Commercial Applications.
5. Conclusion

Diffraction Gratings: the heart of optical spectrometers

Two well-established commercially available diffraction grating fabrication methods :

- With mechanical ruling engine (Ruled Gratings)

Straight grooves

- Recording light interference in photoresist (Holographic Gratings)

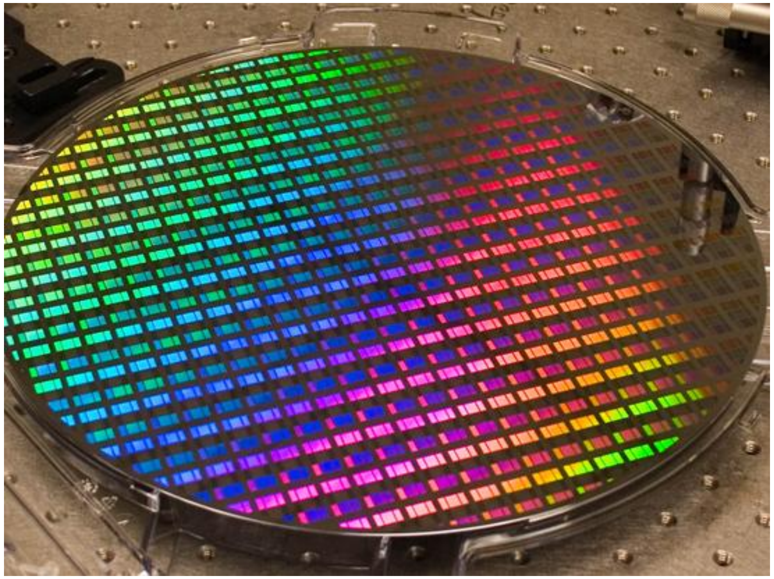
Straight or curvilinear grooves, shape is limited by writing beam.

New Contestant:

Photolithographic Gratings

Arbitrary groove patterns

First significant innovation in grating fabrication in the last 40 years since introduction of holographic gratings



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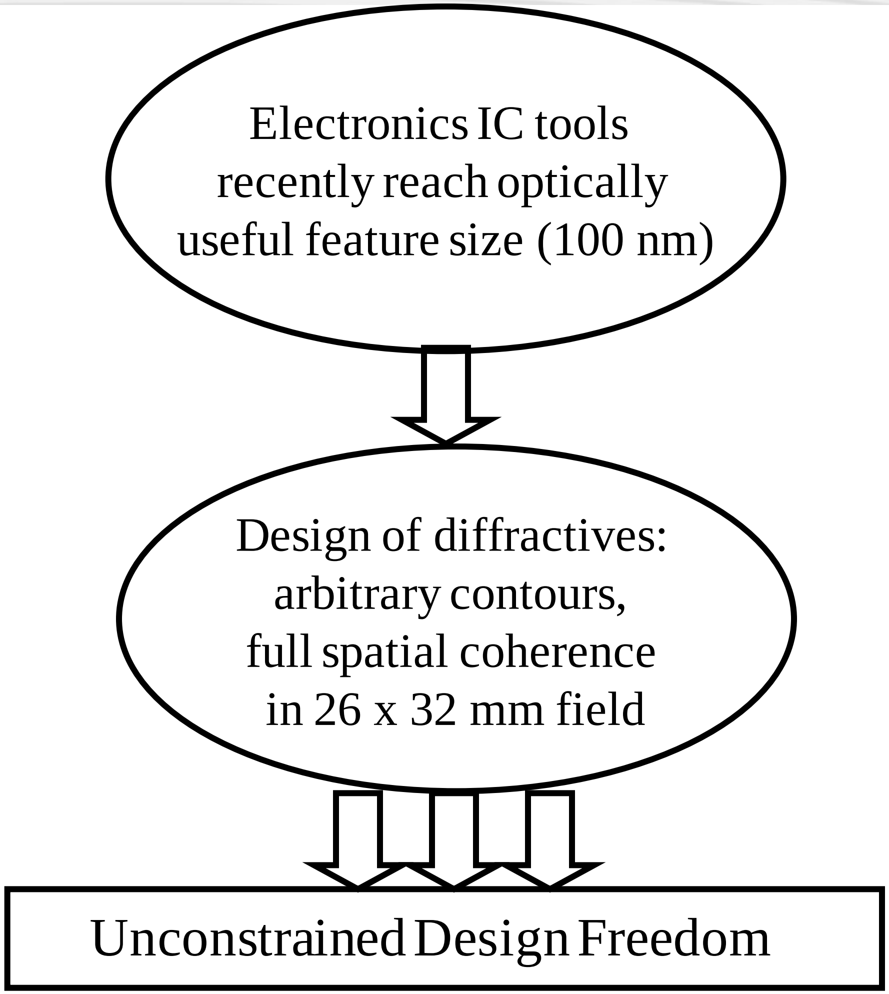
Breakthrough: application of known technology to a new task

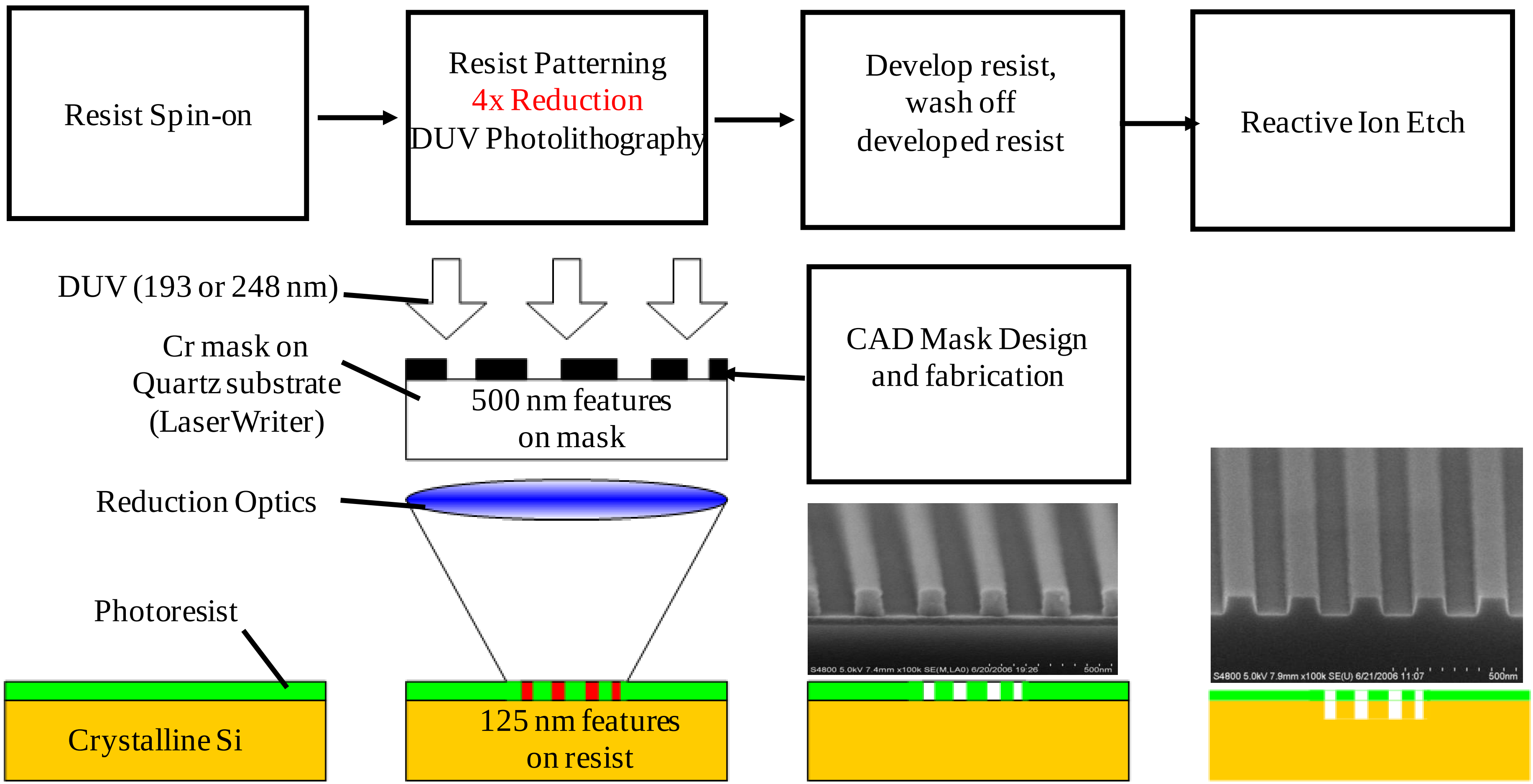


- Unlike older diffraction grating technology, arbitrary groove layout, curvature, spacing.
- Unlike e-beam writers, useful field size of spatial coherence

(26 x 32 mm vs 0.1 x 0.1 mm)

- 65 nm minimum feature size (and shrinking)
- 10^{11}-10^{12} design pixels
- Volume fabrication ready

Photolithographic Nanofab pathway



Mask fabrication: Laser Writer

Micronic Laser Systems AB

- Write time (6” mask) 1 h 45 min
- Minimum main feature 220 nm
- Address grid 1.25 nm
- CD uniformity (global, 3 σ) 7 nm
- Registration (global, 3 σ) 15 nm

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Resist Patterning: DUV Reducing Scanner

- Reduction Factor 4x (from mask)
- Resolution 65 nm
- Field Size 26 X 33 mm
- Throughput 122 wph

  300 mm wafers

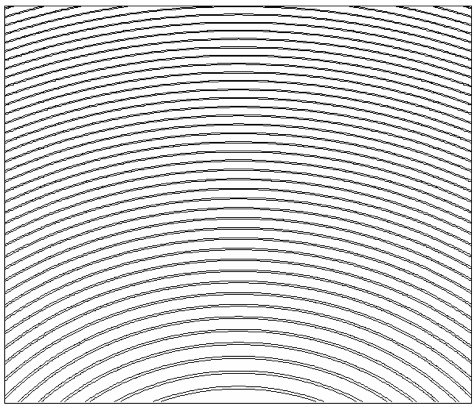
  125 exposures

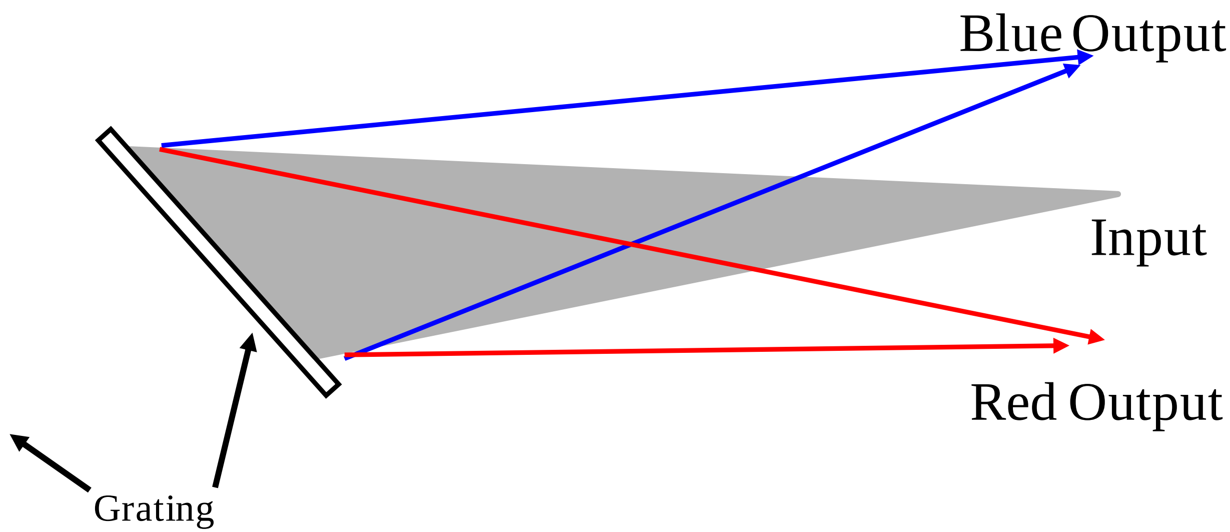
•Exposure wavelength:

248 nm, 193 nm, 193 nm immersion

Possibilities: Focusing Diffractive Gratings

Focusing Grating Surface Profile (schematic)

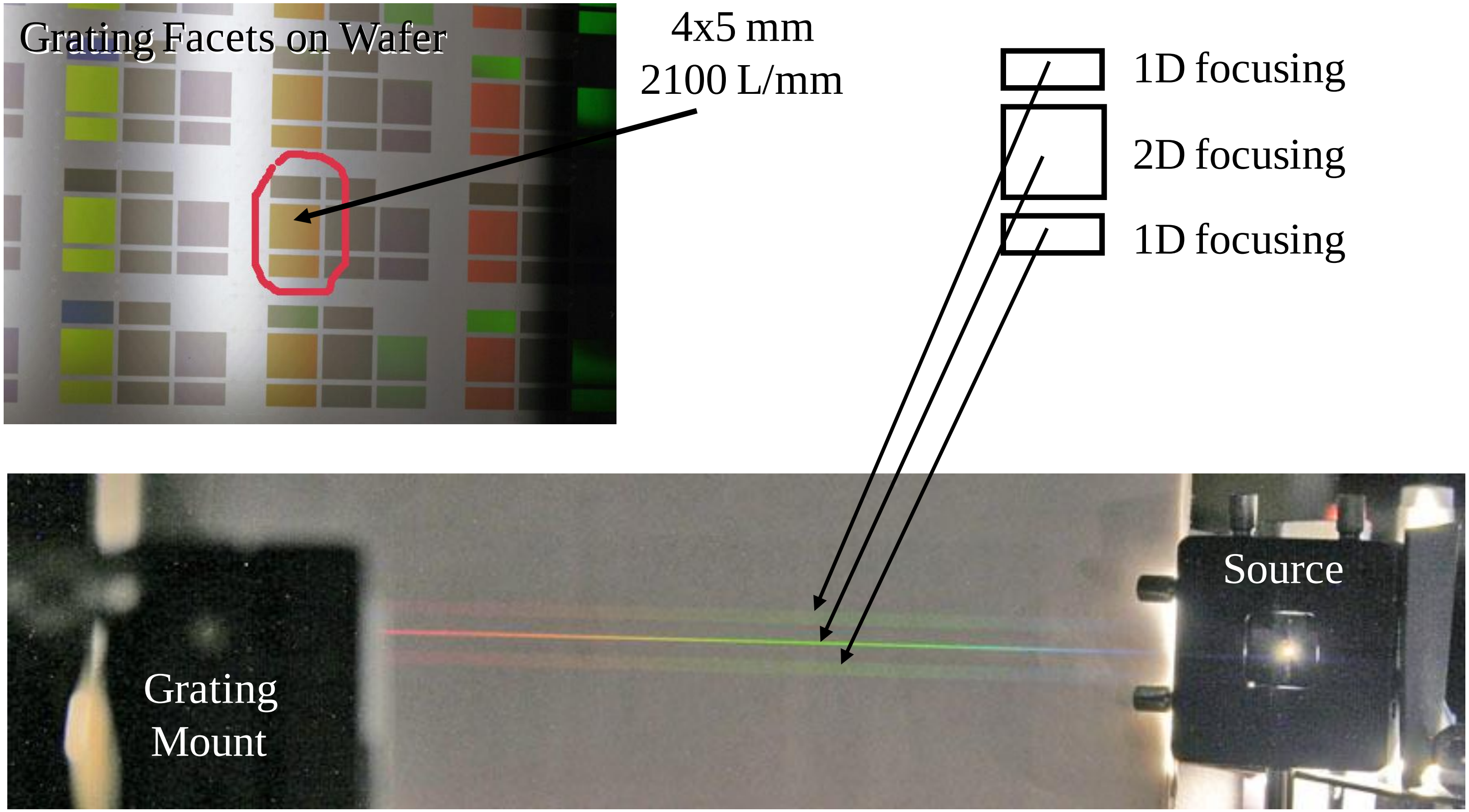




Lithographically-Ruled, Flat, Complex Contour Grating (10^{11} pixels)

Use computer-calculated interference pattern to produce focusing diffraction grating on flat substrate

Demonstrate Flat-Focusing Grating Concept (NASA Phase I SBIR)



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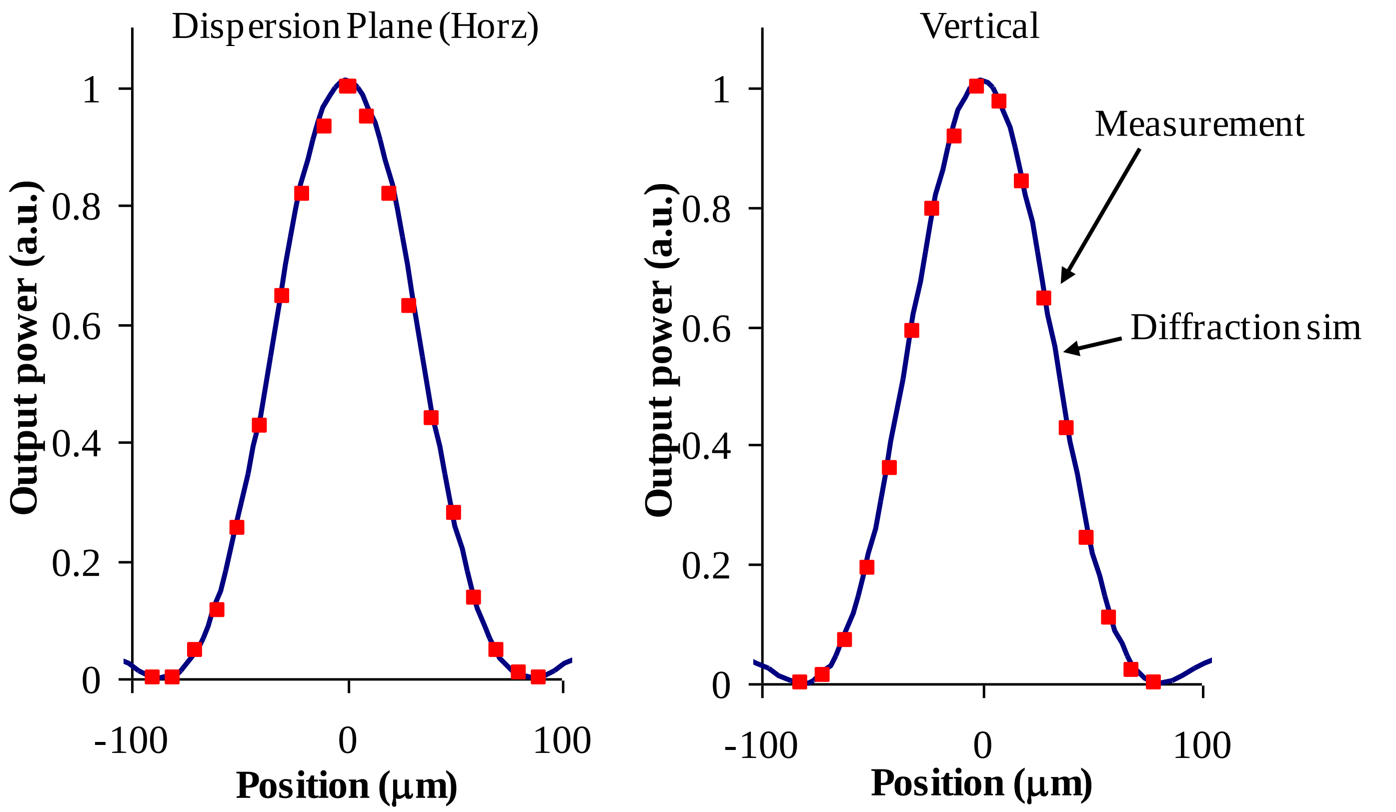
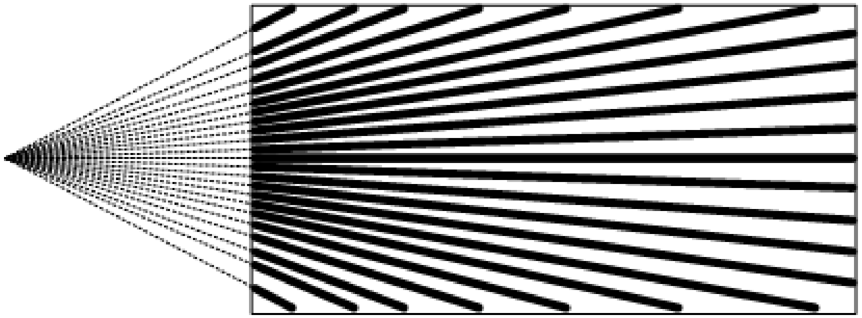
Diffraction-limited Focusing Demonstrated



Constellation-X Off-axis Grating Prototype

Objective: Demonstrate feasibility of technology for X-ray spectrometer

- Design and testing by group of Professor Webster Cash, University of Colorado
- Mask design and fabrication: LightSmyth



This type of gratings was proposed in 1980th by Dr. W. Cash but no fabrication means were available at that time.

- Offers better resolution per unit area and better aberration control than conventional in-plane grating –> flight weight reduction
- Cannot be fabricated by interferometric or mechanical ruling, but trivial in mask-based fabrication
- Line density 4000 l/mm, higher density will be required for final product

Grating for NEXUS

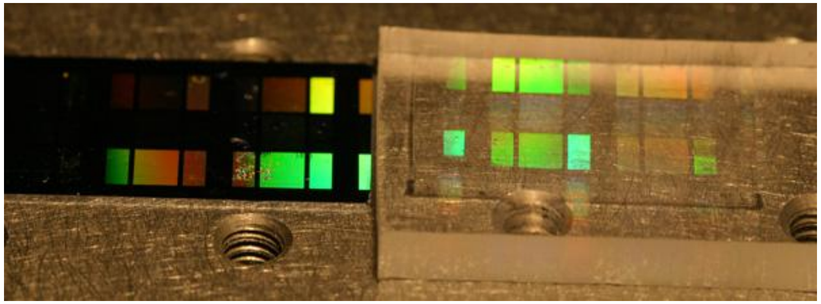
(Normal incidence EUV spectrometer to study outer atmosphere of Sun)

Objective: provide product meeting NASA specification of NEXUS grating

Challenging design task: wavelength range 45.7-80 nm. Achromatic focusing requires curved grooves with variable line spacing on cylindrical substrate.

- Successful demonstration will open pathways to very flexible aberration control methods.

Proposed pathway: use replication technology



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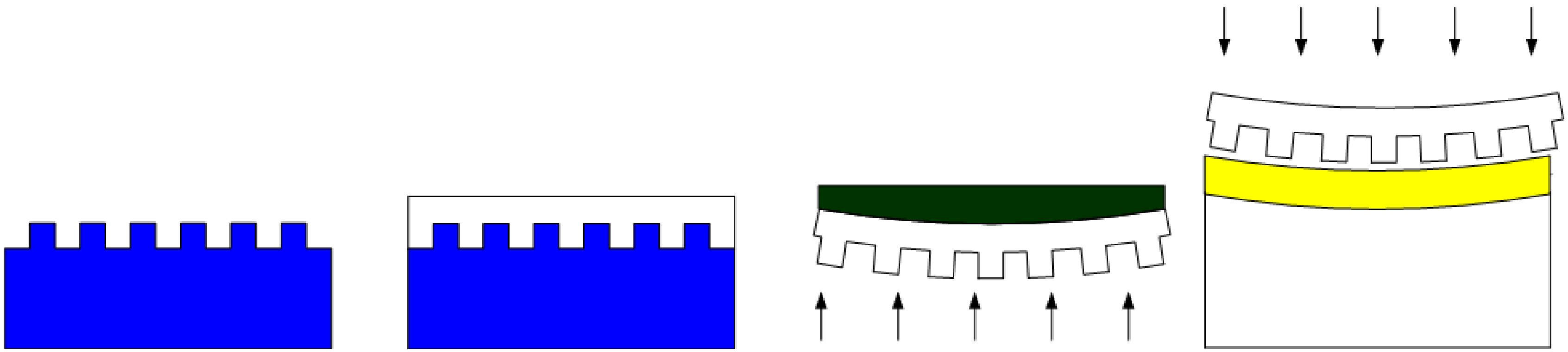
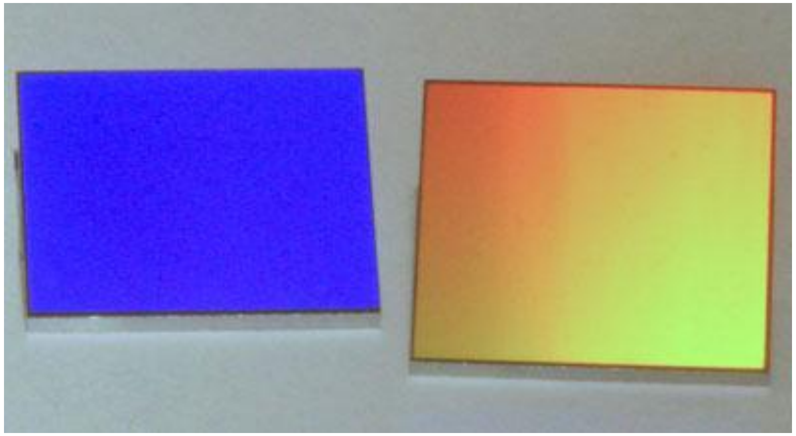
Grating for NEXUS (cont): fabrication pathway

Pattern and etch grooves on silicon wafer → Replicate on thin deformable substrate (polymer or electroformed Nickel shin → Map the flat substrate on cylindrical mandrel → Produce final grating replica



Each of the basic fabrication blocks is well established.

Silicon Substrate Gratings commercially offered by LightSmyth



3600 lines/mm	Coating:
2400 lines/mm	Al + MgF2
1200 lines/mm	Bare Si

Conventional straight groove gratings on silicon substrate:

- Substrate TEC better than that of PIREX
- Thermal conductivity close to that of aluminum
- Free of replication defects
- Robust and cleanable
- Thin (0.7 mm) and lightweight
- Volume-produced, inexpensive

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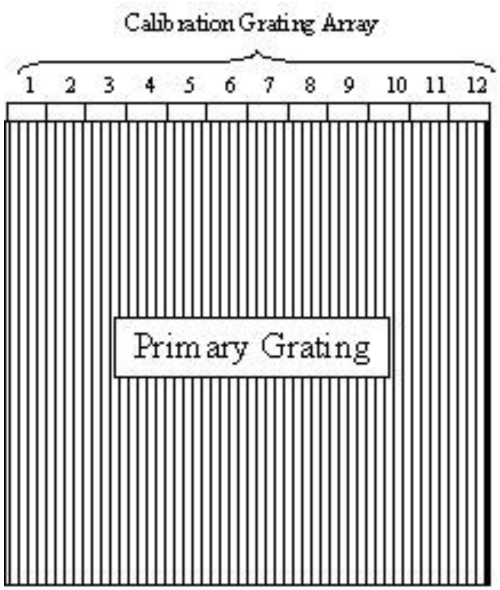
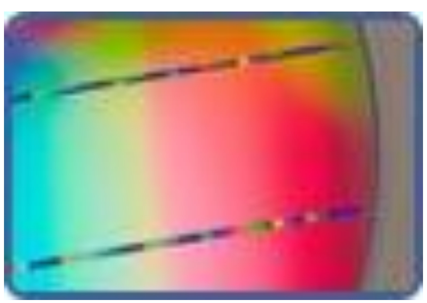
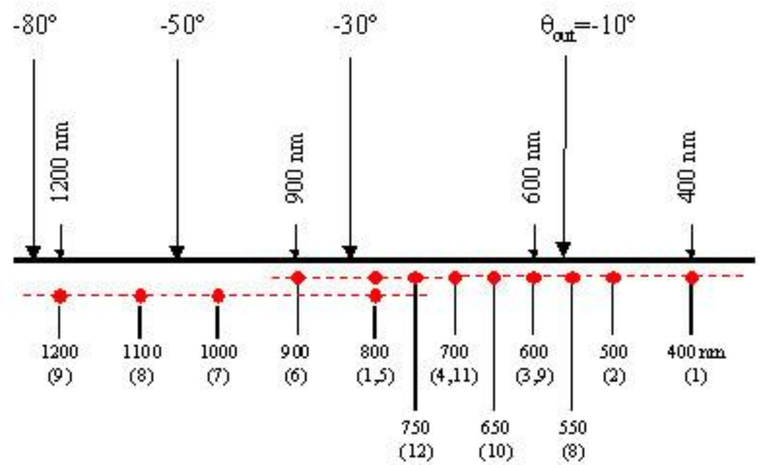




Gratings with calibration markers:

Reference wavelength source provides athermal wavelength reference and linear dispersion in the focal plane.



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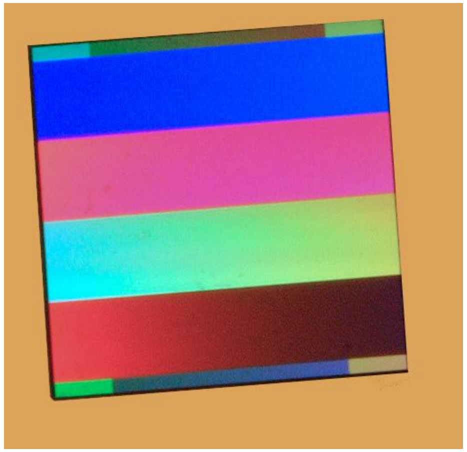

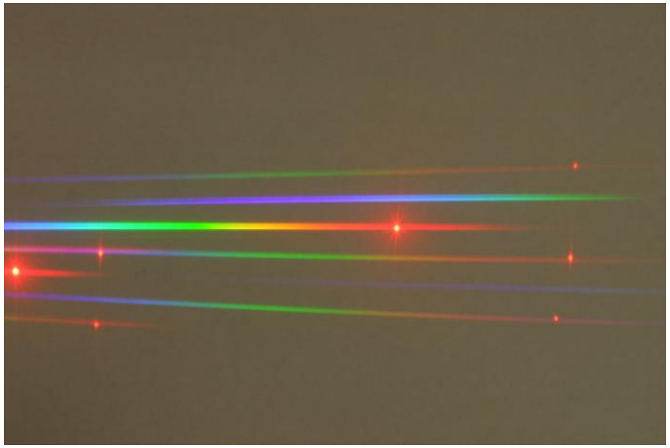

2D dispersion in focal plane

Grating Arrays:

• High resolution spectrum acquisition with a single grating element

•Contains four individual high-resolution gratings, each had grooves tiled at different angle.

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"LightSmyth Jewels"

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Summary

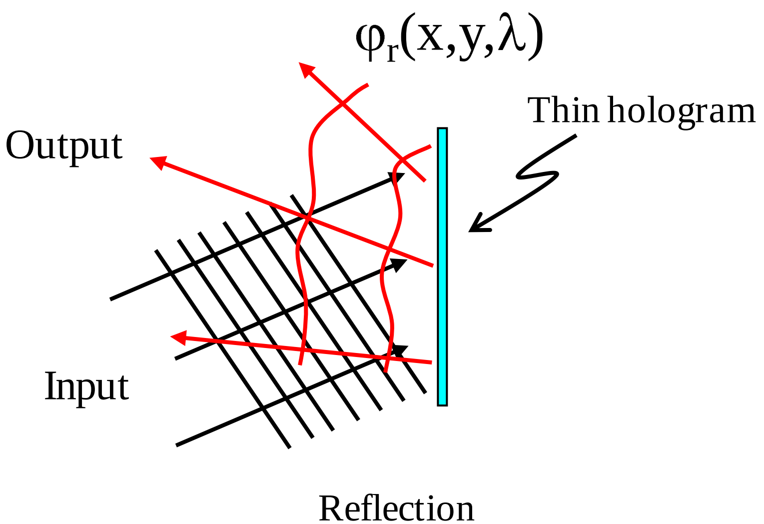
- New fabrication process opens multiplicity of new powerful applications for dispersive diffractive elements
- Useful in multiple NASA programs
  - Constellation-X
  - Nexus
  - Others
- Need to create more awareness among optical designers to define "killer" applications and develop off-the shelf simulation software
- First commercial efforts is well underway:

  www.LightSmyth.com

Thank You!

Special thanks to NASA SBIR program and our technical monitor David Content for continuous support.

1. Mask Design: Arbitrary wavefront transformation from flat optic



- Single flat element provides focusing/imaging PLUS dispersion
- Requirements
  - arbitrary diffractive pattern
  - resolution better than $\approx\lambda/4$ ($\approx$100 nm visible)
  - spatial coherence over aperture
- Fabrication Approaches
  - Past – interferometric exposure
  - Future Opportunity
    - compute
    - laser write
    - reduce via photolithography