Precision Shaping, Assembly and Metrology of Foil Optics for X-ray Reflection Gratings

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OUTLINE

- Reflection grating substrate geometry requirements:
  - In plane
  - Off plane

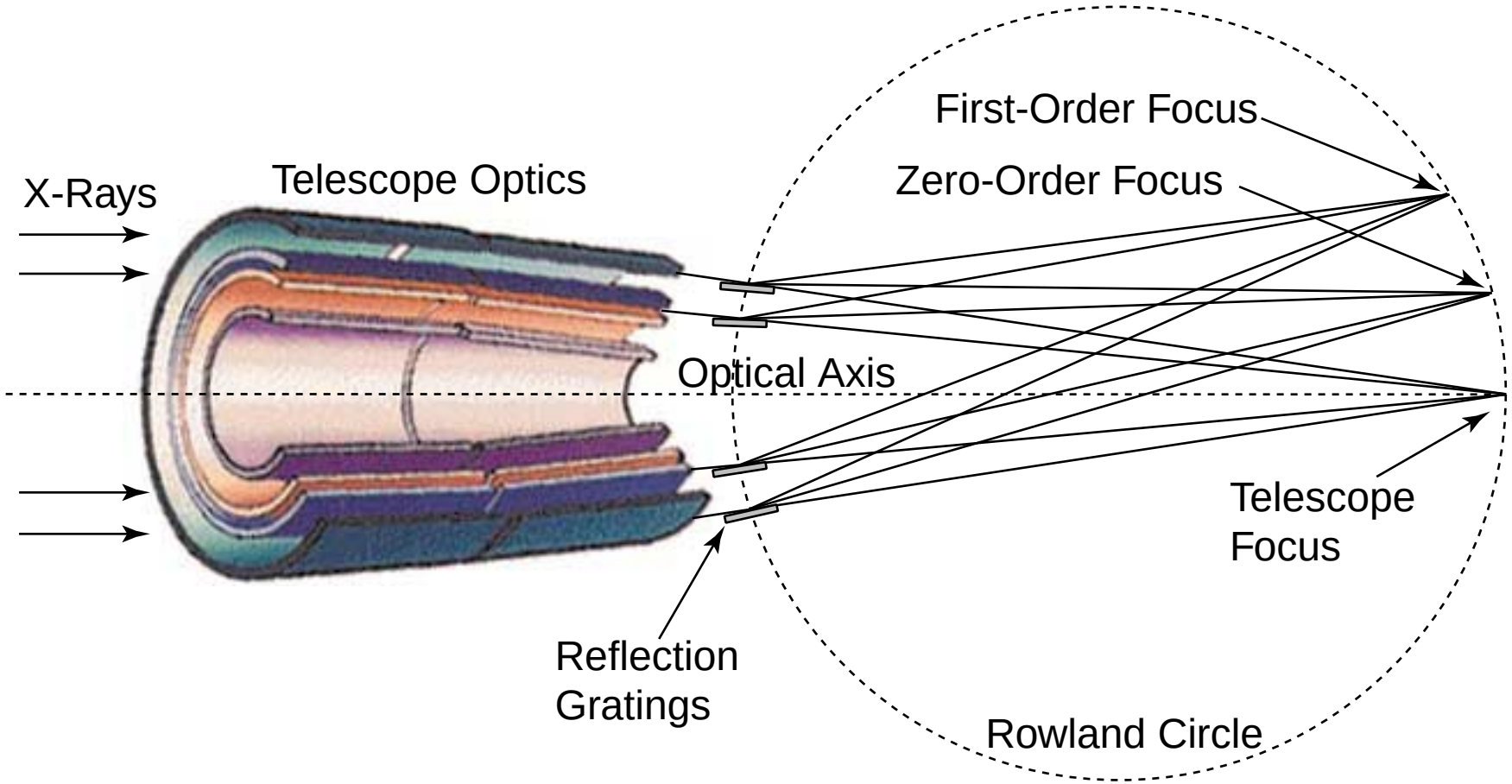
- Grating patterning technology:
  - Interference lithography
  - Nanoimprint lithography
  - Anisotropic silicon etching

- Foil optic shaping technology results:
  - Magneto-rheologic fluid (MRF) polishing

- Foil optic shape metrology:
  - Deep-UV Shack-Hartmann topography

- Precision grating assembly:
  - Silicon microstructures
  - Assembly truss

Wolter Telescope Reflection Grating Optics



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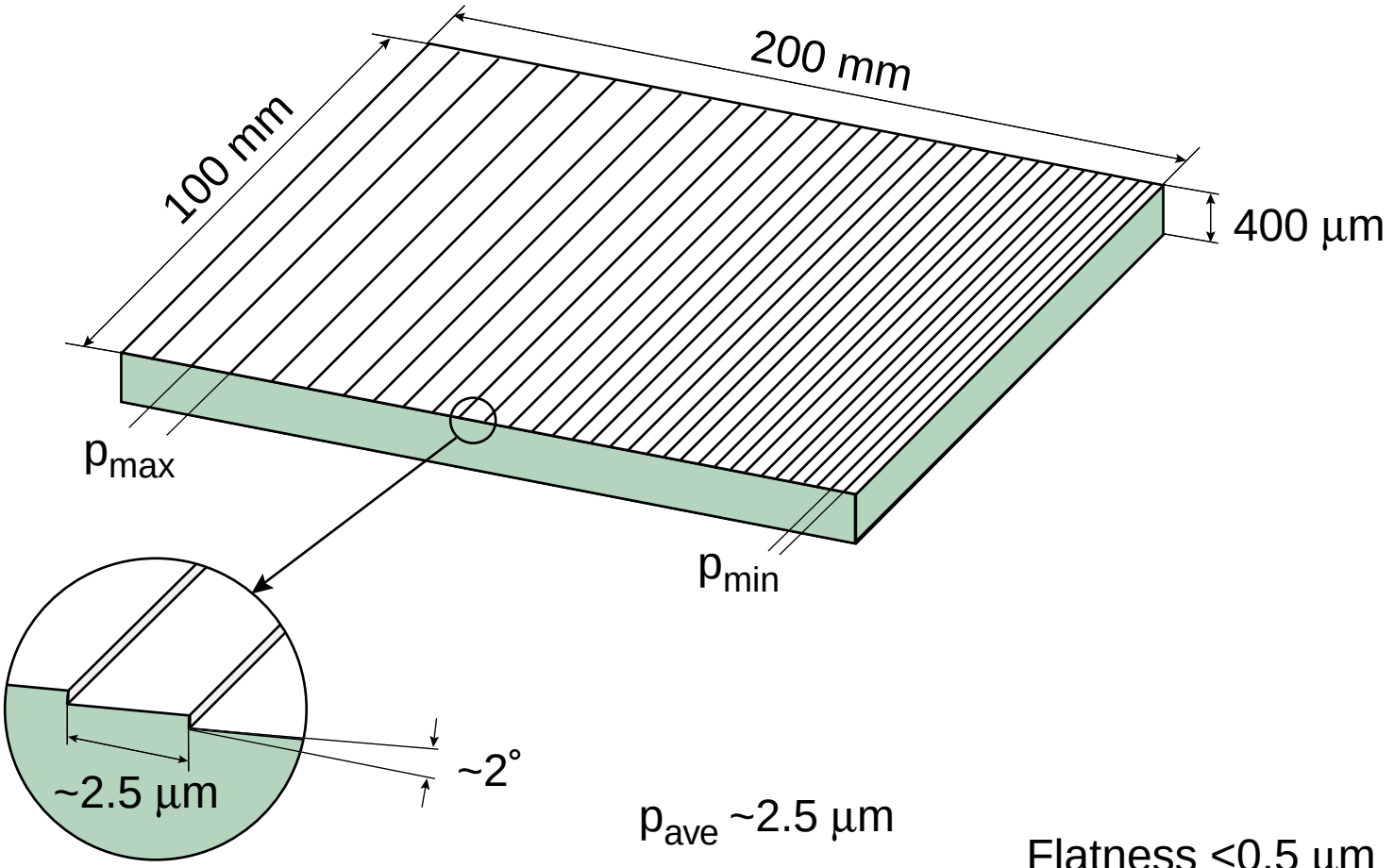
X-ray Reflection Grating Geometry
(In-Plane Diffraction)



p_{ave} ~2.5 μm

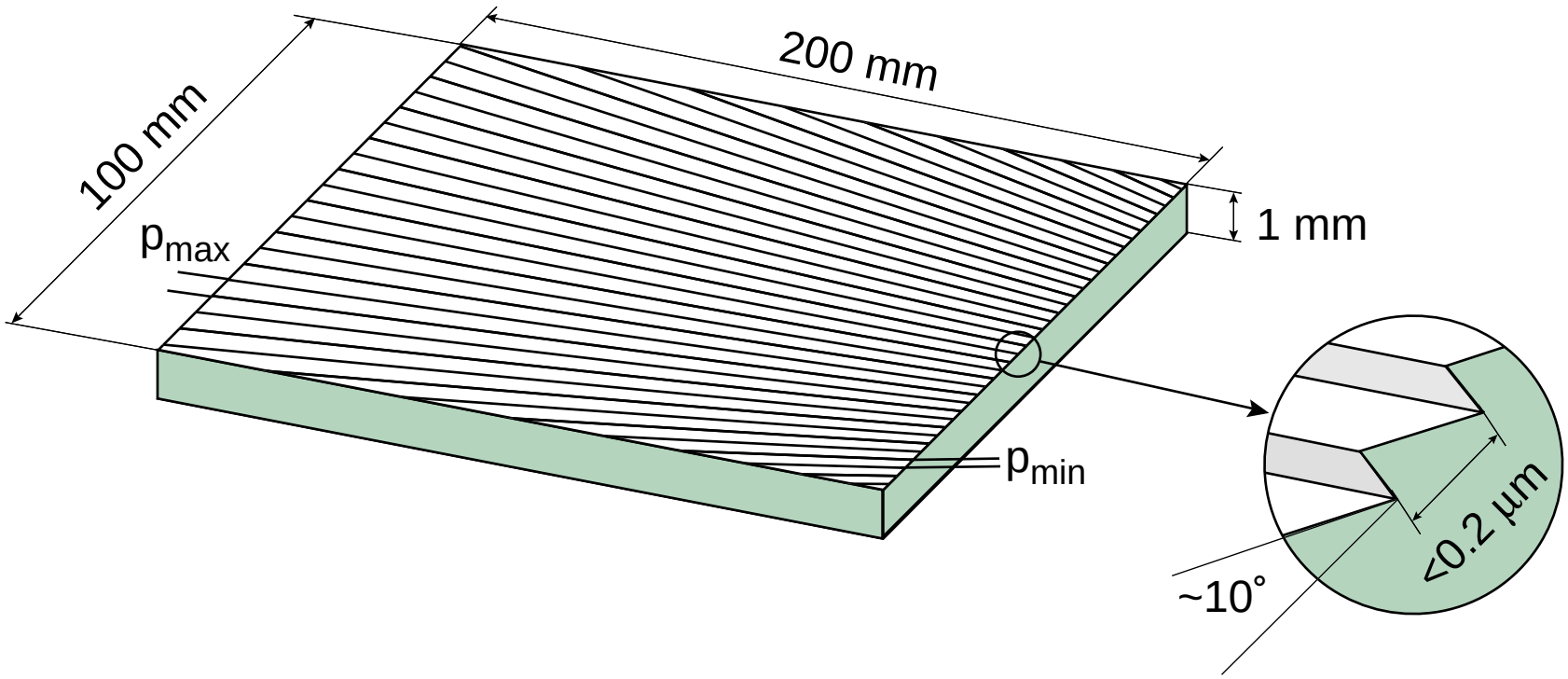
Chirp $\Delta p/p$ ~5%

Blaze ~2°

Flatness <0.5 μm

Roughness <0.5 nm

X-ray Reflection Grating Geometry
(Off-Plane Diffraction)



p_{ave} <0.2 μm

Chirp Δp/p ~2%

Blaze ~10˚

Flatness <1.0 μm

Roughness <0.5 nm

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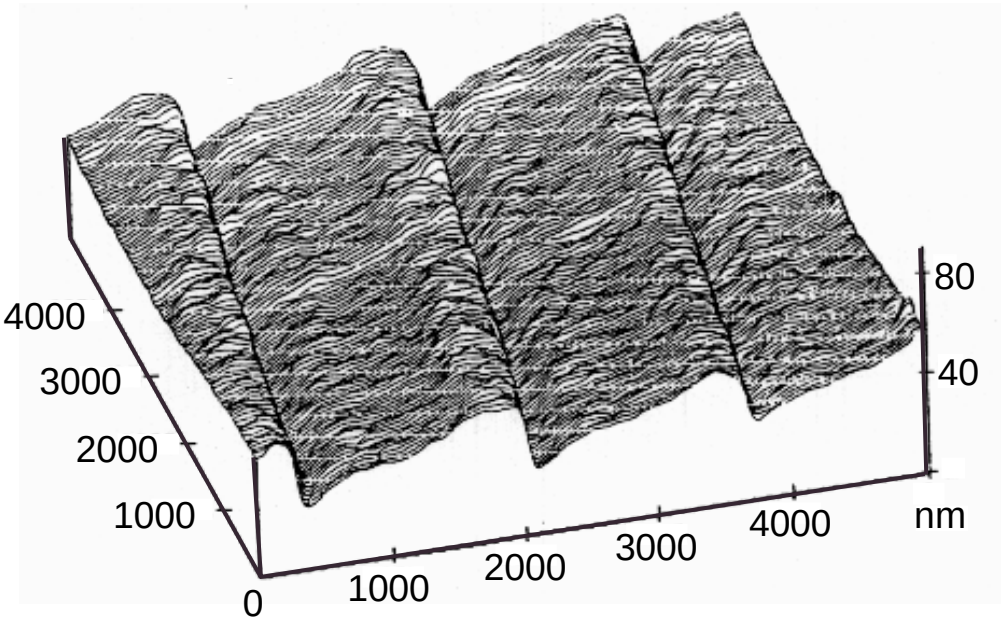
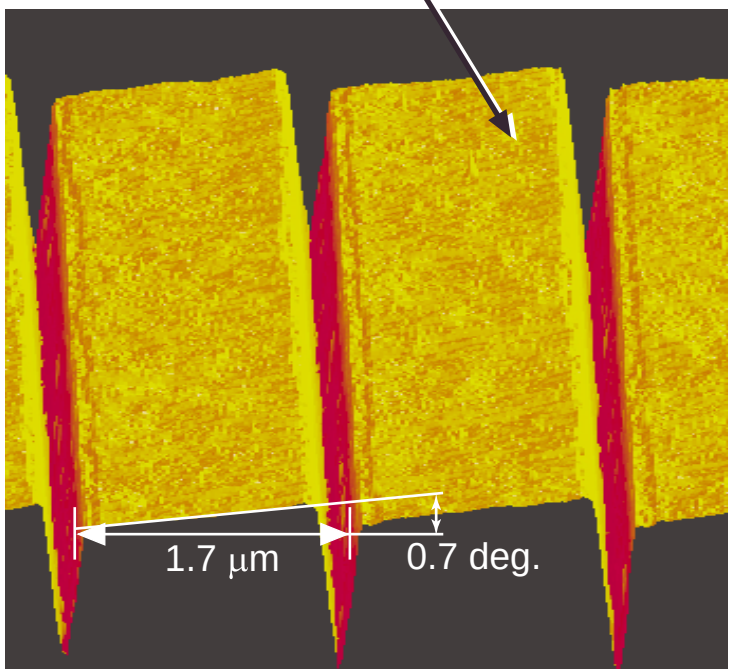
Super Smooth Reflection Grating Fabrication Results



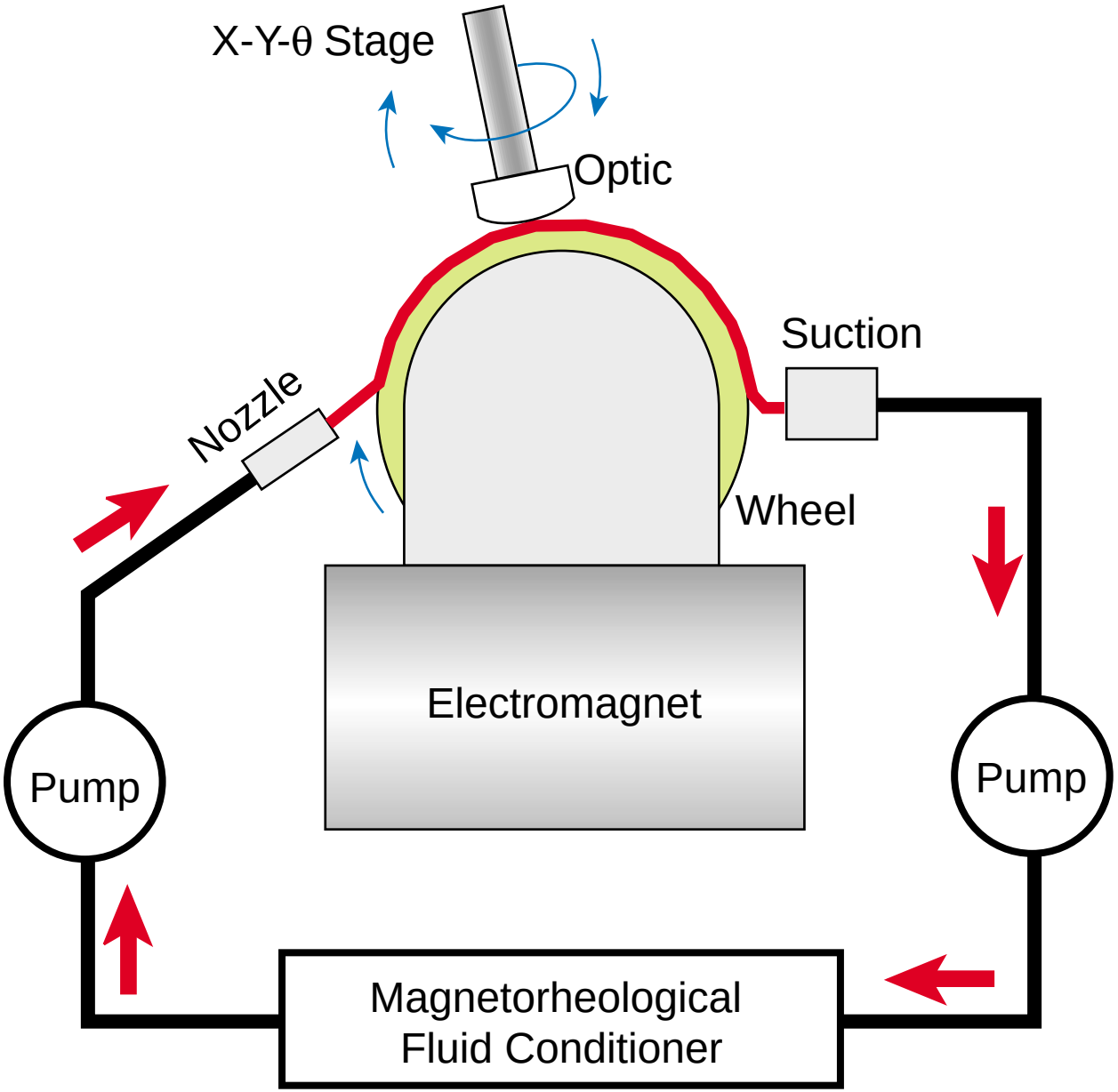
Mechanically Ruled and Replicated
(XMM Grating - Old Technology)

Si (111) planes,
<0.4 nm rms roughness



Anisotropically Etched
(MIT Grating - New Technology)

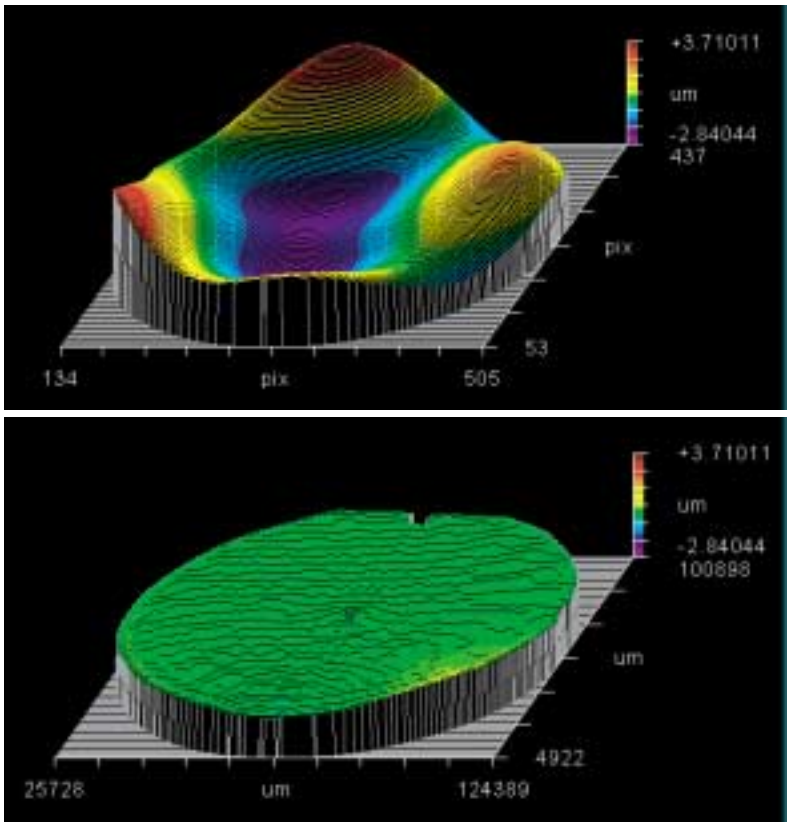
Principle of Magneto-Rheologic Fluid Polishing



Wafer polishing results with MRF

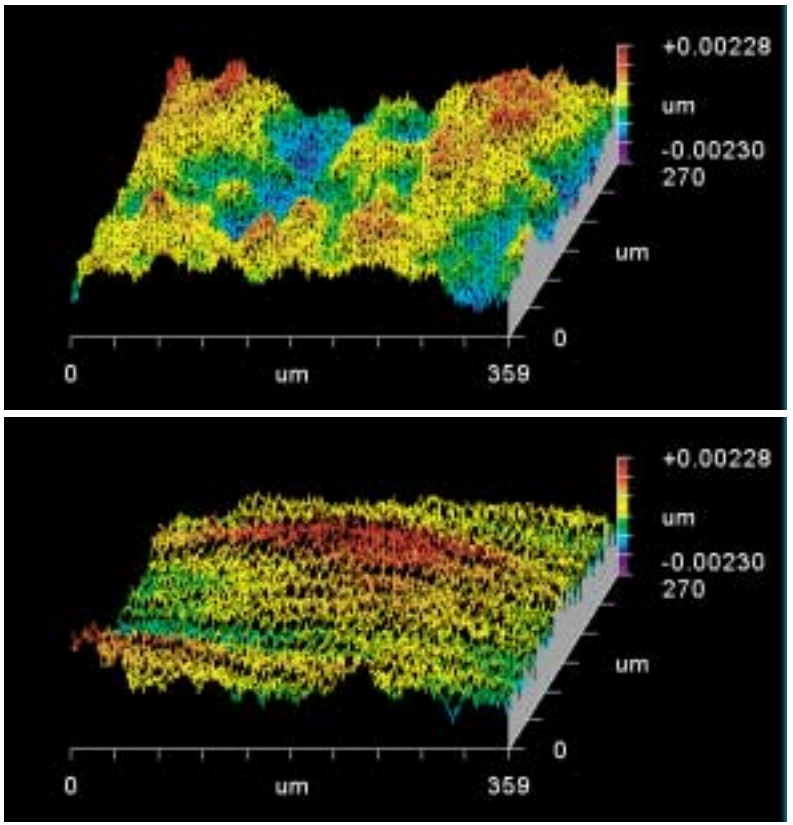
QED Technologies

Bow & Warp



Before **-** 6.55 µm ***After*** **-** 0.81 µm

rms microroughness



Before 0.66 nm ***After*** 0.64 nm

Material:	Silicon
Diameter:	100 mm
Thickness:	0.45 mm

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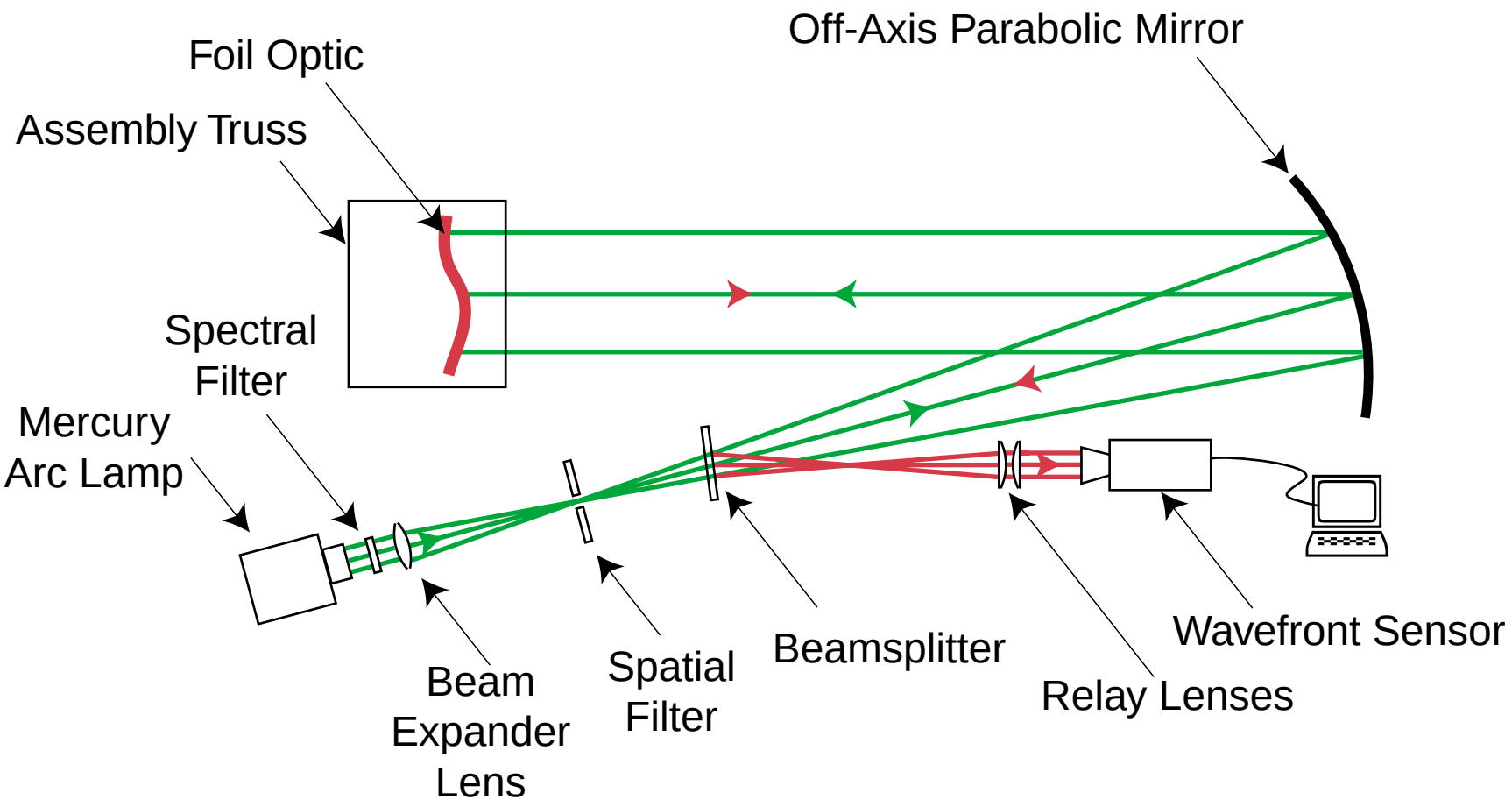
Shack-Hartmann Surface Metrology Tool



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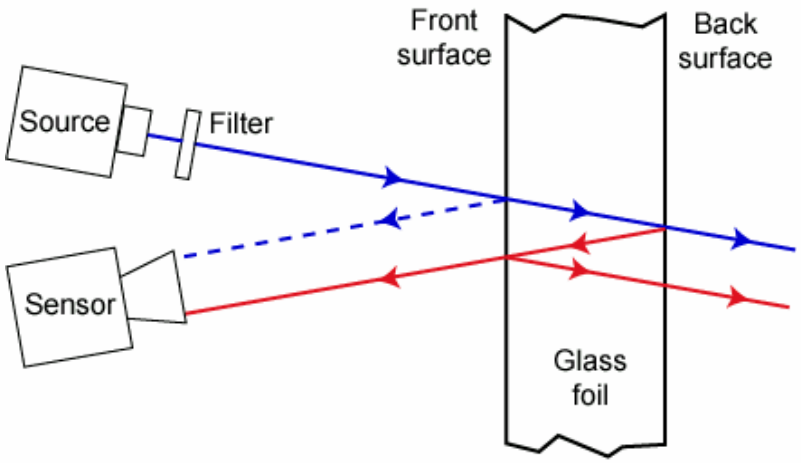
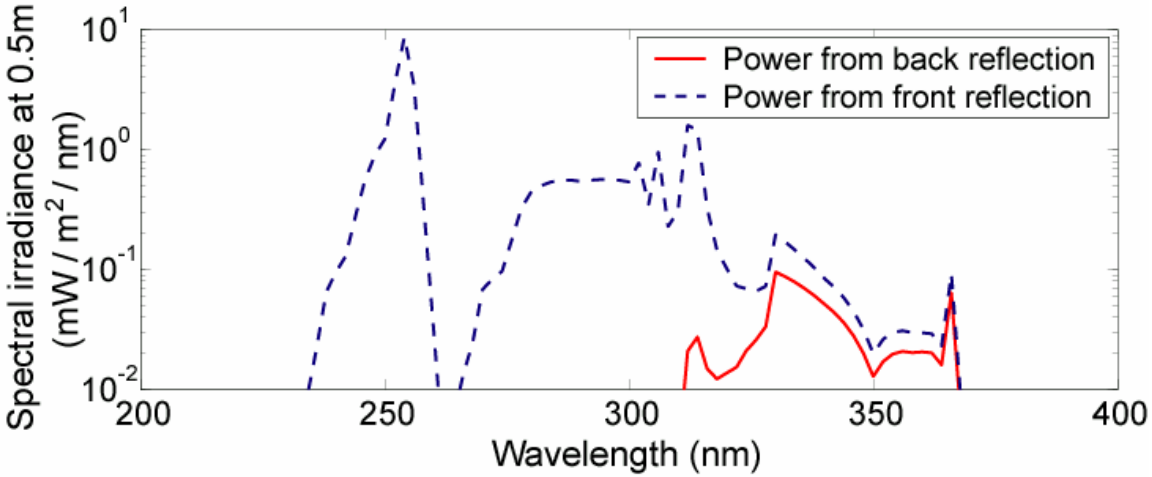
Detailed Design Considerations

Spectral Filtering



- Source irradiance
- Spectral filter transmittance
- Glass optical properties

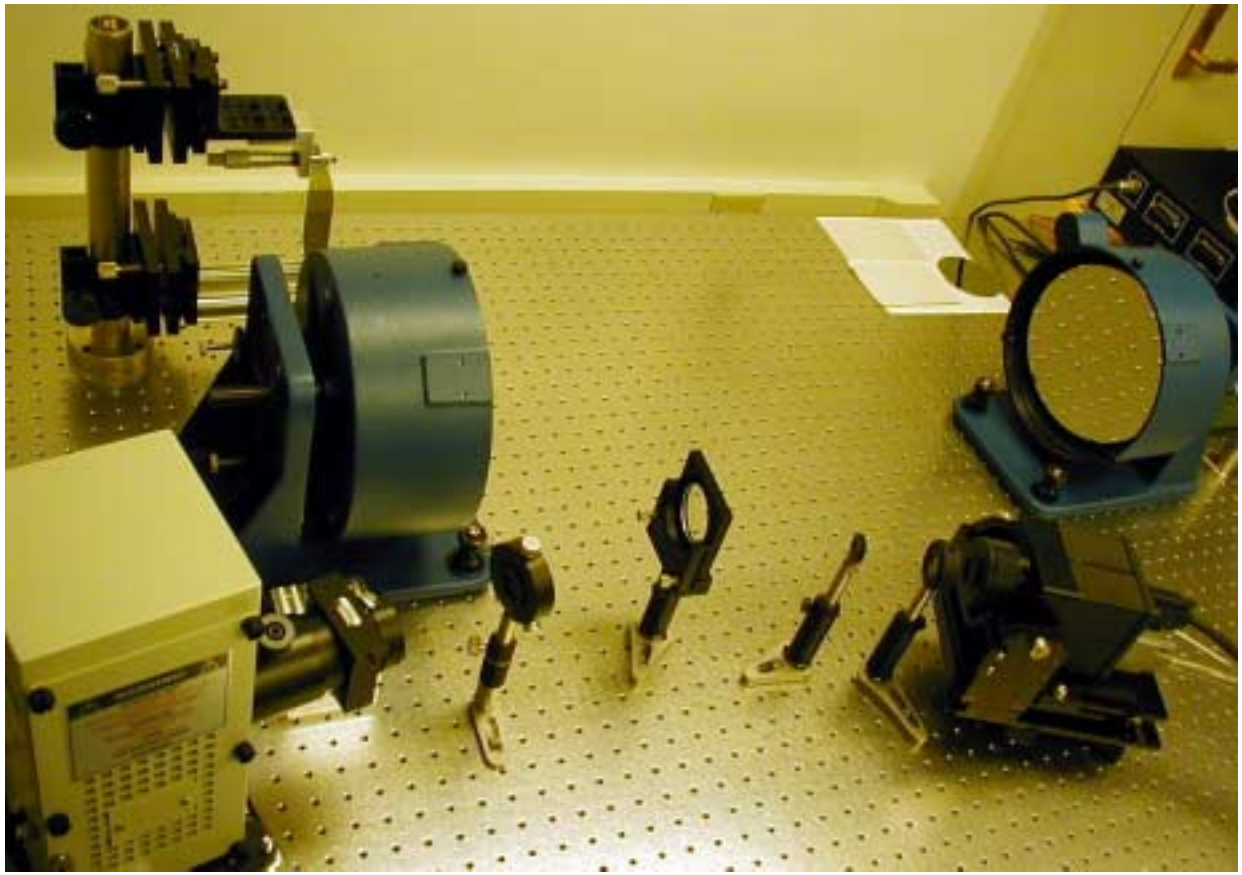


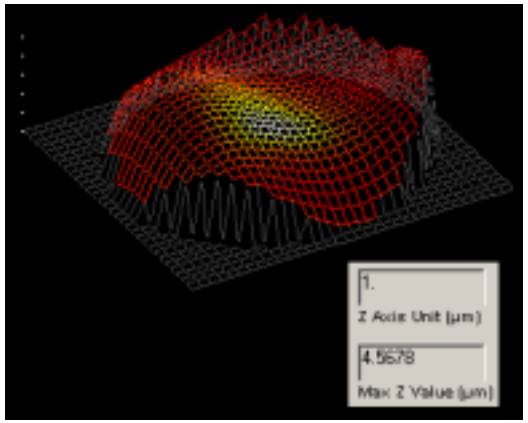
Performance Evaluation

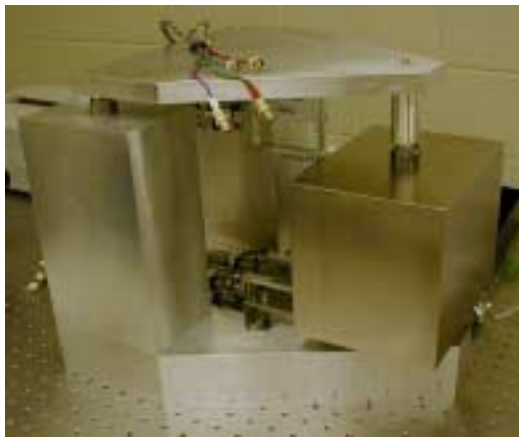
Setup	Statistic	P-V (nm)	RMS (nm)
Static Repeated measurements	Range	5.0	0.5
Repeatability Removed and replaced object	Range	35.6	14.0
	Std. Dev.	13.2	5.1
Accuracy Compared two known surfaces	Average	TBD	<16.7

Application

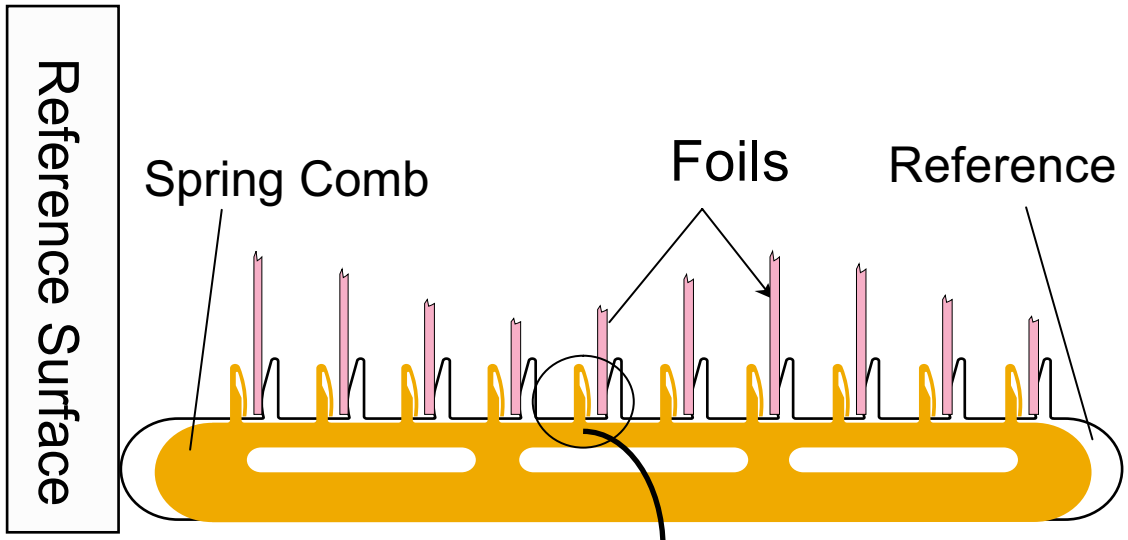
Will meet SNL foil surface metrology needs for >3 years



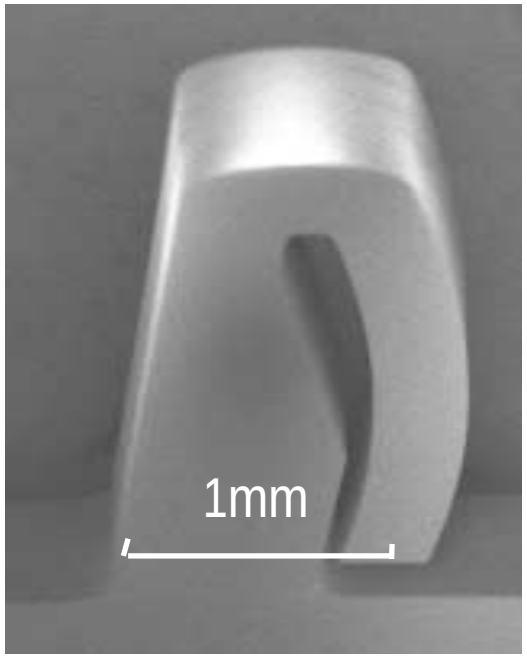


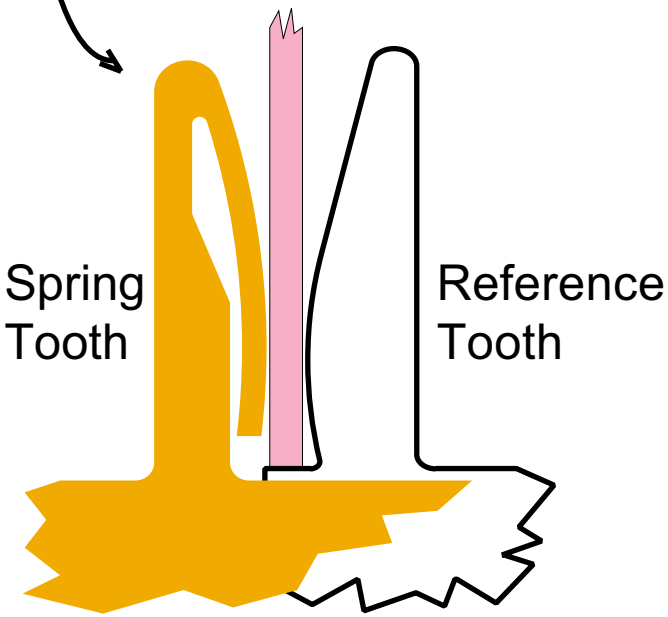


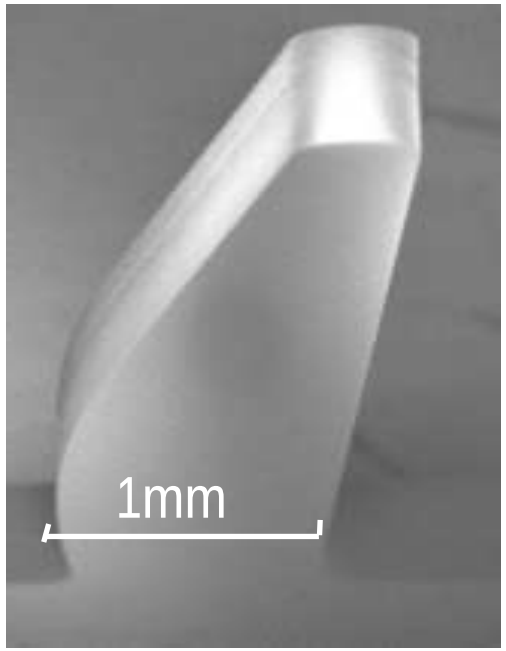
Silicon Microcombs Establish an Accurate Metrology Frame



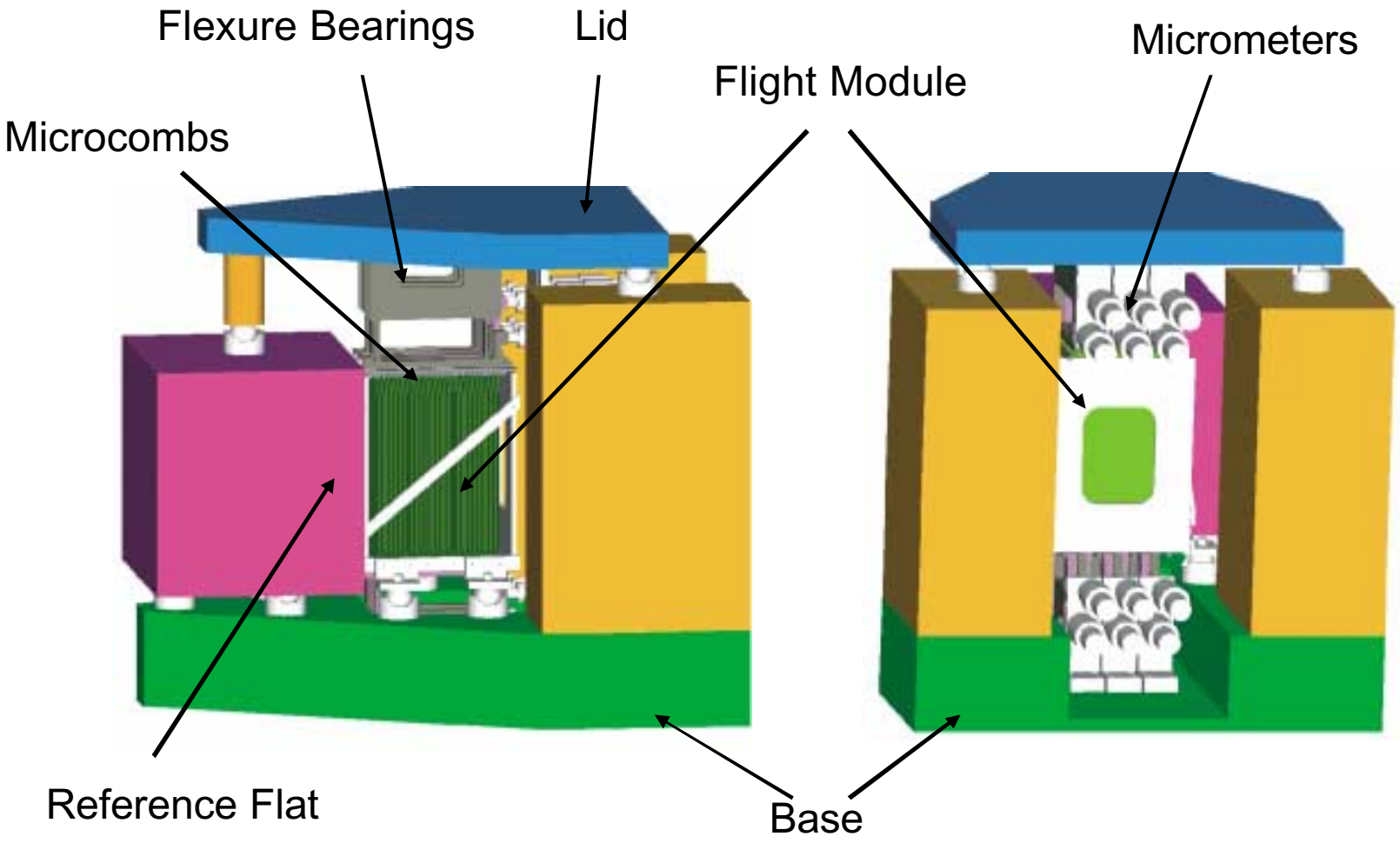
Scanning Electron Microscope Images of Microcomb Teeth





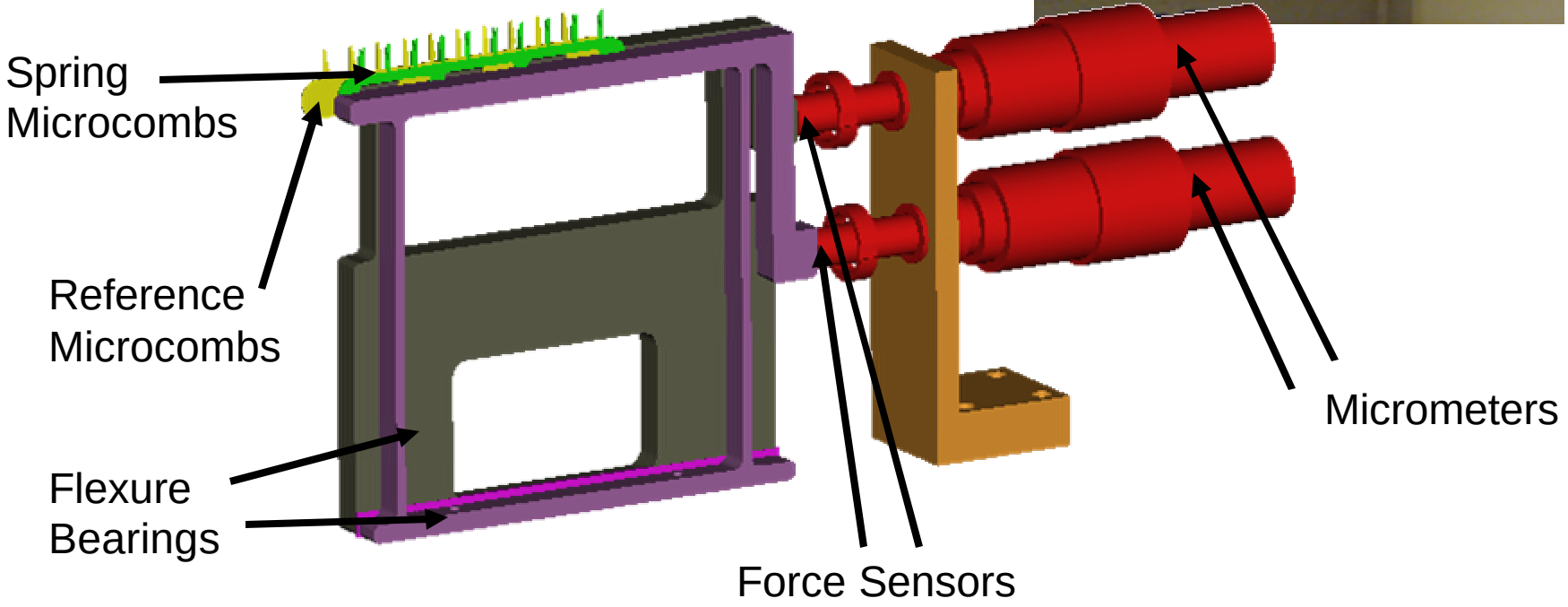


Assembly Truss Concept



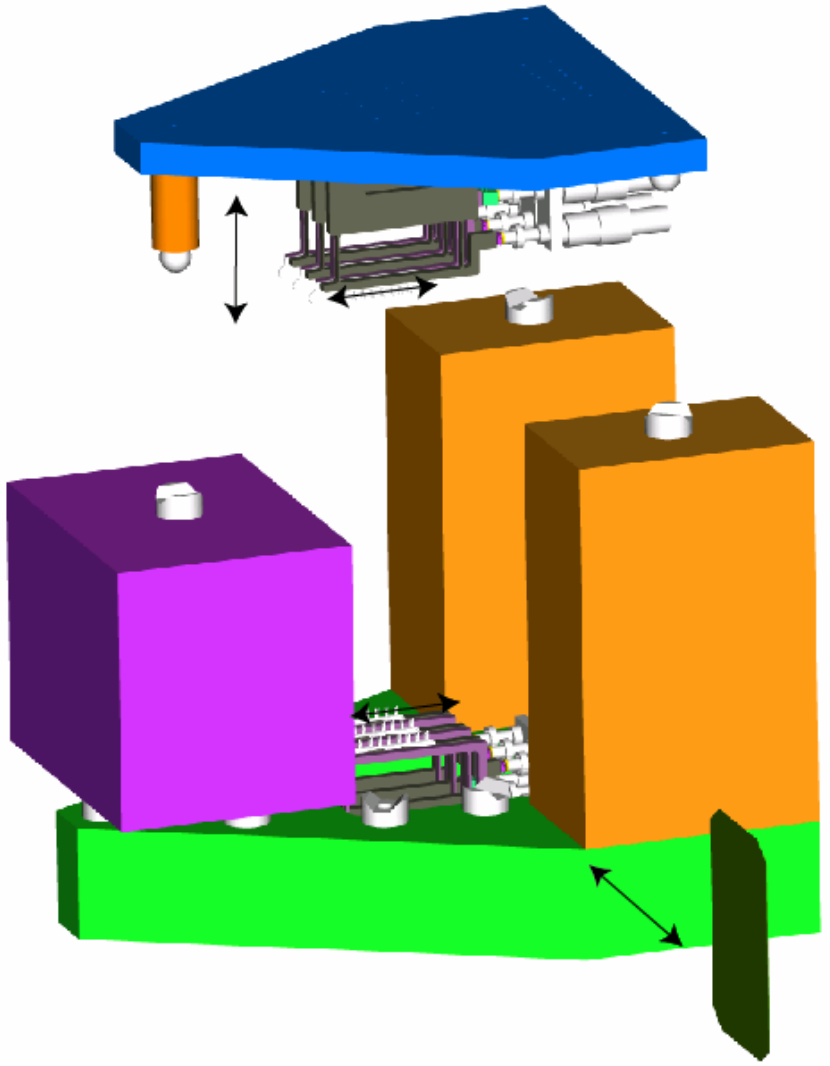
Comb Actuation

- Need to move combs until they touch the reference flat
- Hertz contact stresses detectable
- 0.1µm actuation capability
- No hysteresis motion



Precision assembly

Single slot repeatability test displacement error one sigma (μm)			
0.4 mm thick Si wafer		3 mm thick Quartz plate	
Pitch	Yaw	Pitch	Yaw
0.34	0.36	0.33	0.30



Conclusion

- Developing technology for both in-plane and off-plane reflection grating pattering.
- Several promising foil optic shaping technologies under development.
- Improved surface metrology (deep-UV Shack-Hartmann) will enable rapid progress.
- Developing foil optic assembly technology using precision silicon microstructures.

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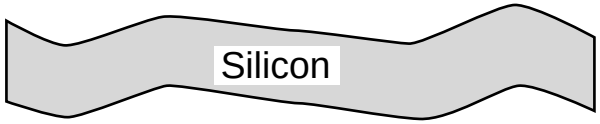
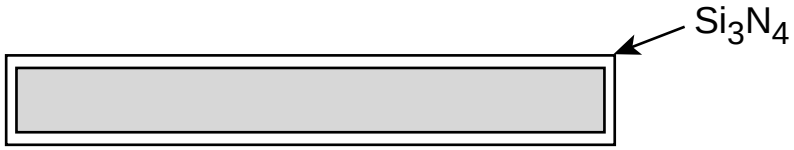
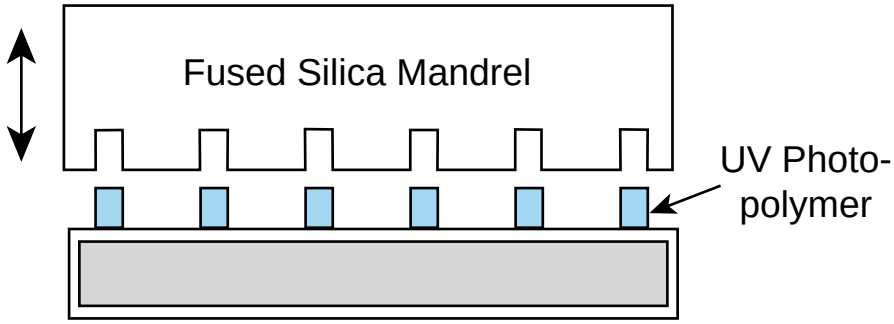
Reflection Grating Fabrication
Process Overview



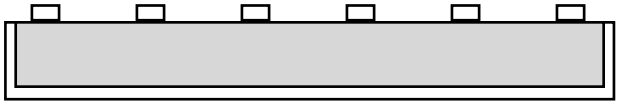
1) Procure off-cut silicon wafers.



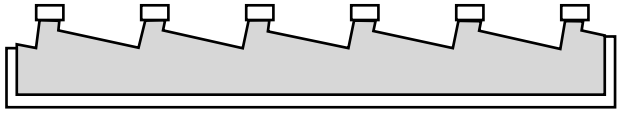
2) Flatten wafers and coat with silicon nitride.



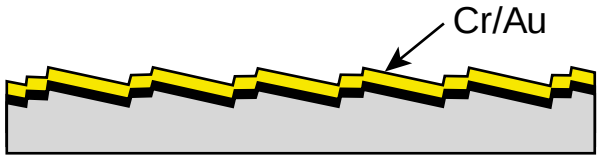
3) Replicate grating by UV nanoimprint lithography.



4) Plasma etch nitride and strip resist.



5) KOH etch silicon.



6) Strip nitride, trim nibs and sputter metal.

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