Low-Stress Silicon Cladding for Surface Finishing Large UVOIR Mirrors

Phase II Final Results & Commercialization Update

SBIR Phase II Contract No. NNX14CP14C

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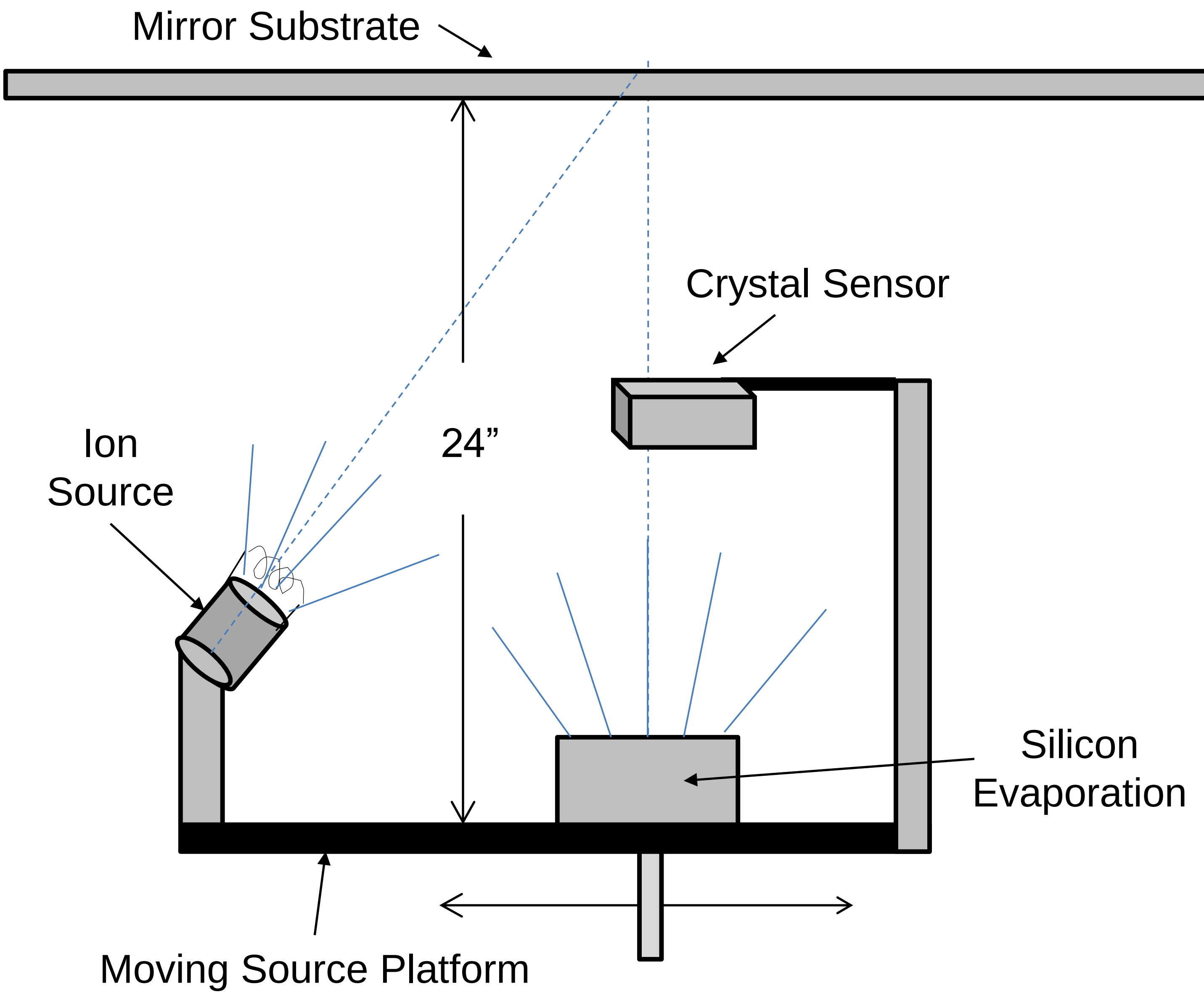
11/1/16

Preview

- Brief background
- Results of the Phase II
- The complicated issue of coating defects and scatter
- Commercialization opportunities
- Plans for continued development

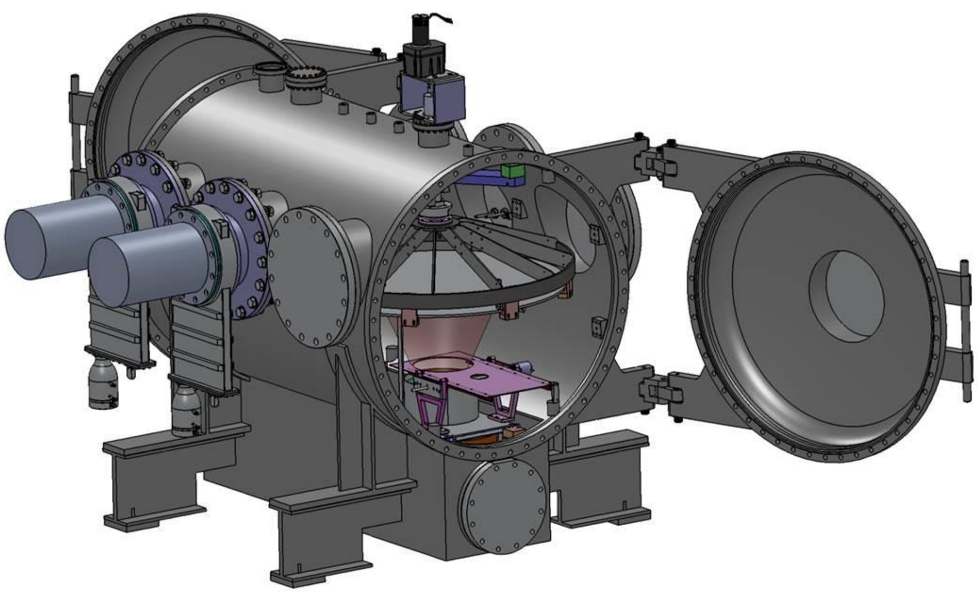
Significance of the innovation

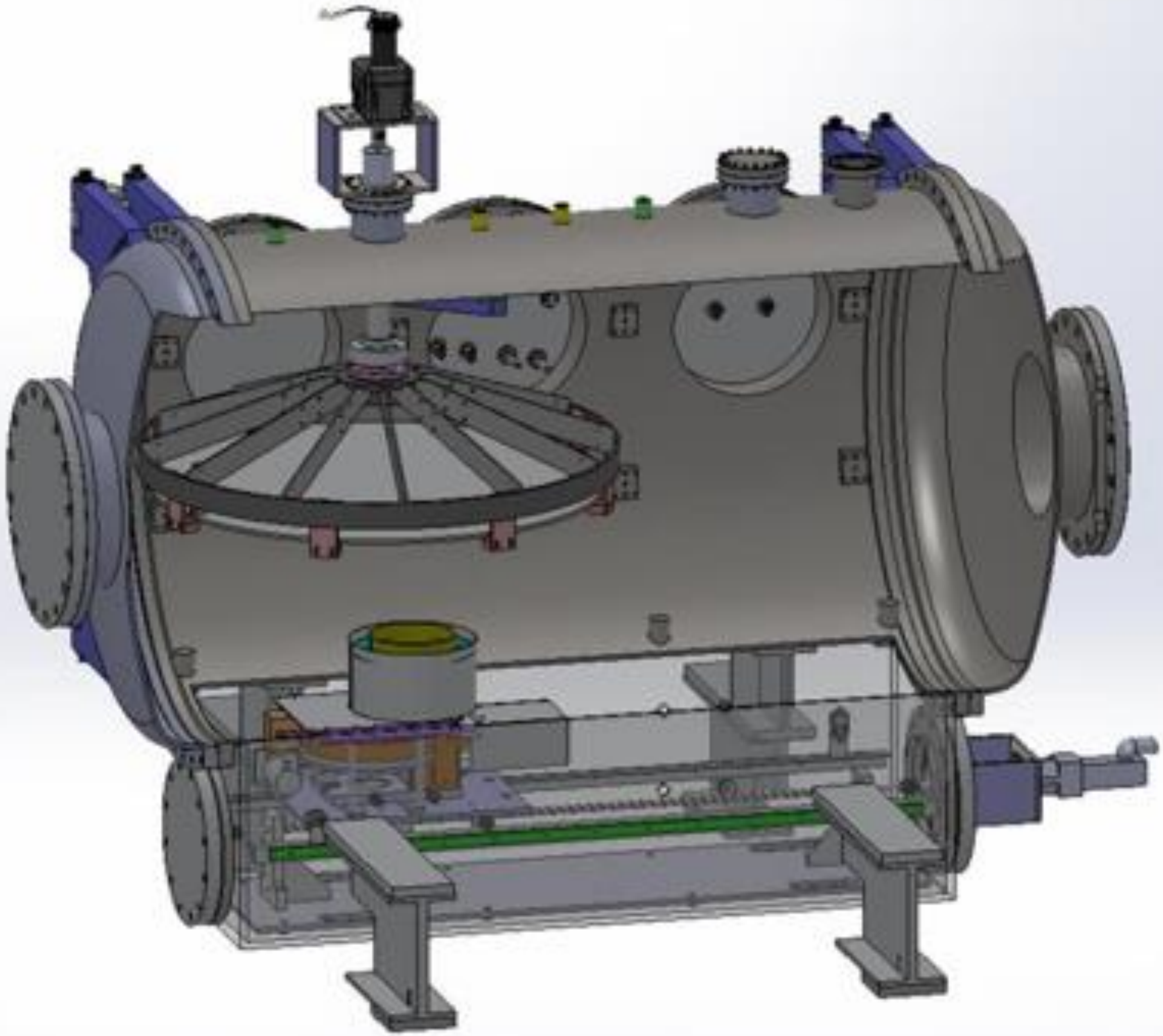
- A method to apply a mirror-quality surface on silicon carbide or other surface that doesn't polish well by itself
  - Scalable process for mirrors several meters in diameter (e.g. 8-meters in diameter)
  - Low-temperature process for bonded mirror assemblies (< 100° C)
  - Low-stress coating for lightweight mirrors ~100 MPa)


Mirror Substrate
Crystal Sensor
Ion
Source
24”
Silicon
Evaporation
Moving Source Platform

1.2-m vacuum coating chamber

Completed in March 2013, the chamber utilizes an ion-assisted e-beam evaporation system.





Commercialization: Si cladding chamber for optics up to 30-cm in diameter (30-microns/day)

ZeCoat Si cladding processes

Type 1: Stacked tensile and compressive layers

- Lower and more repeatable stress (less than 75 MPa typical) with rates of ~50 A/sec
- Problems related to non-homogeneous layers or “tree rings” (polishing differences between the layers)

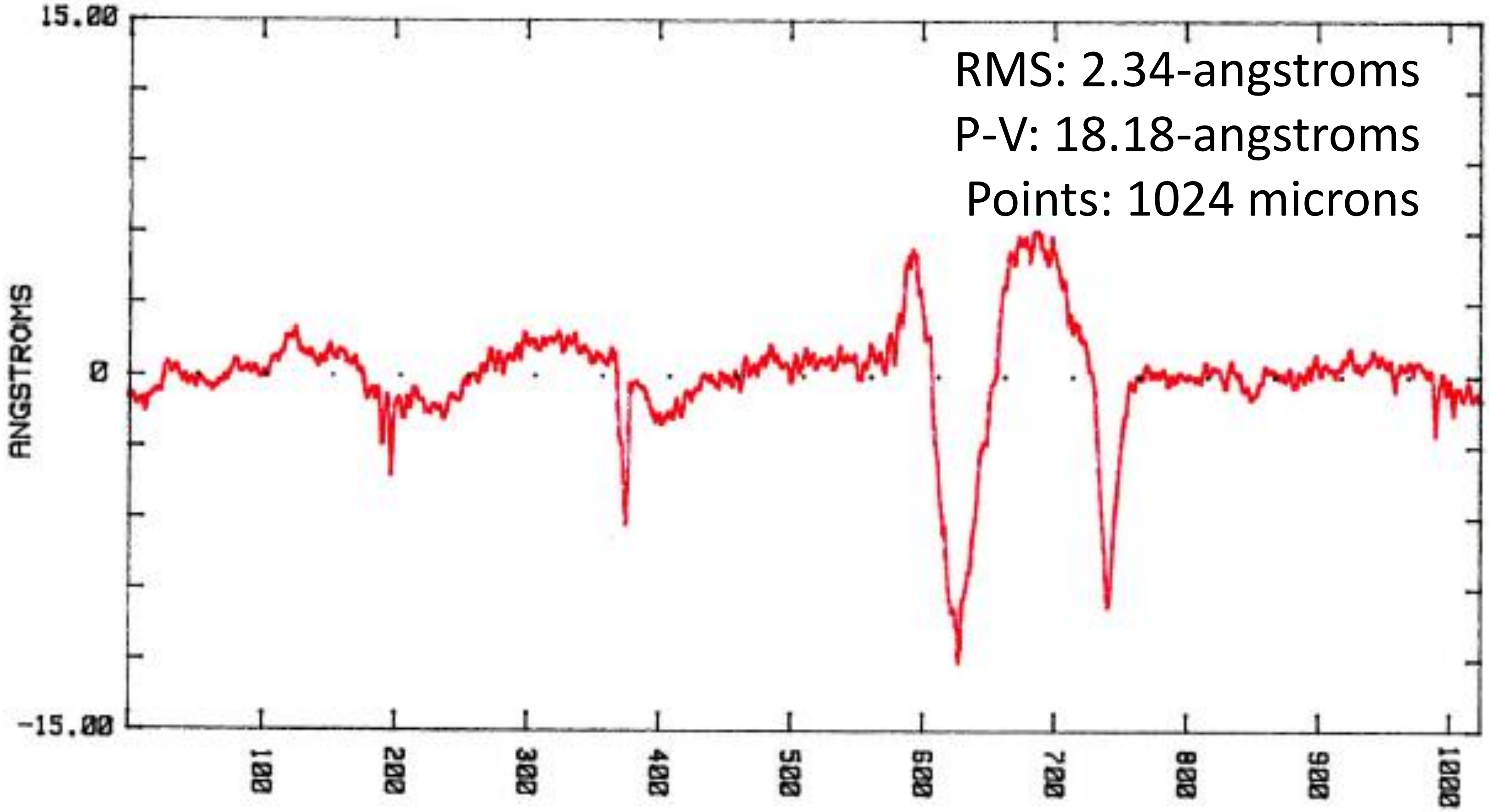
Type 2: Single layer with homogeneous properties through the thickness

- Faster process (80 A/sec)
- Uniform density, uniform stress relief, uniform polishing
- More difficult process to control stress and achieve repeatable stress results (< 150-MPa). This compares to CVD cladding process stress of ~400 MPa

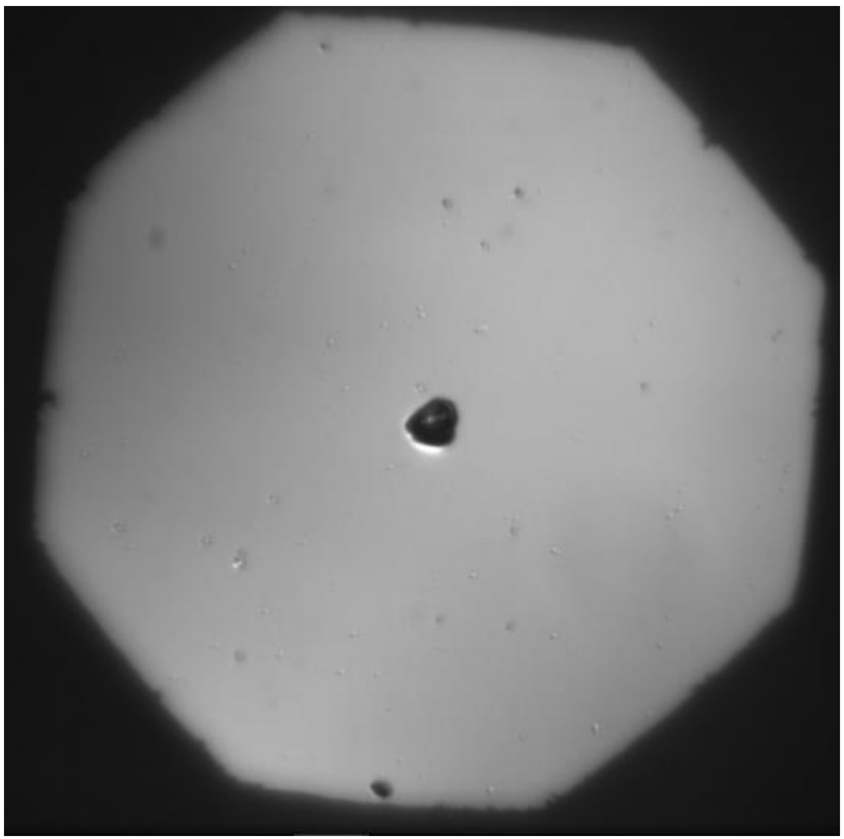
Process metrics

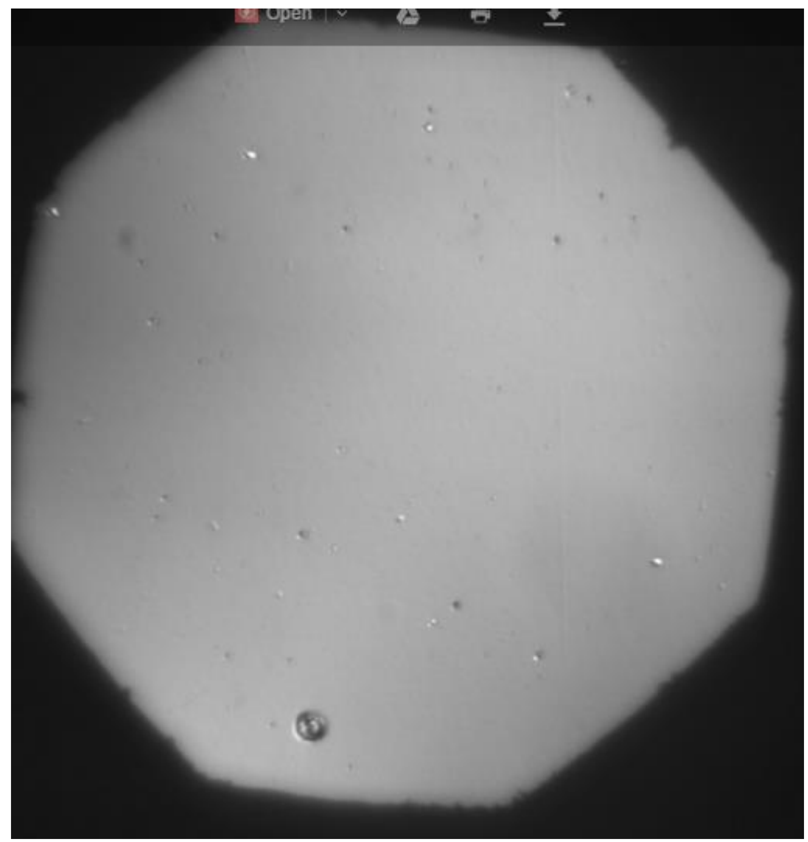
	Metrics					
	Roughness (RMS)	Stress (Mpa)	Rate (A/sec)	Surface Defects	Temp	Thickness
Goal	< 5-angstroms	< 85 MPa	17 A/sec (end phase I)	60/40 scratch-dig	< 100 C	>25 microns
Type 1 - layered	< 2-angstroms	< 75 MPa	50 A/sec	47k, 10 to 20-micron /square meter	< 100 C	> 100 microns
Type 2 - continuous	< 2-angstroms	< 150 MPa	80 A/sec	47k, 10 to 20-micron /square meter	< 100 C	>100 microns

Measurement of surface micro-roughness after CMP



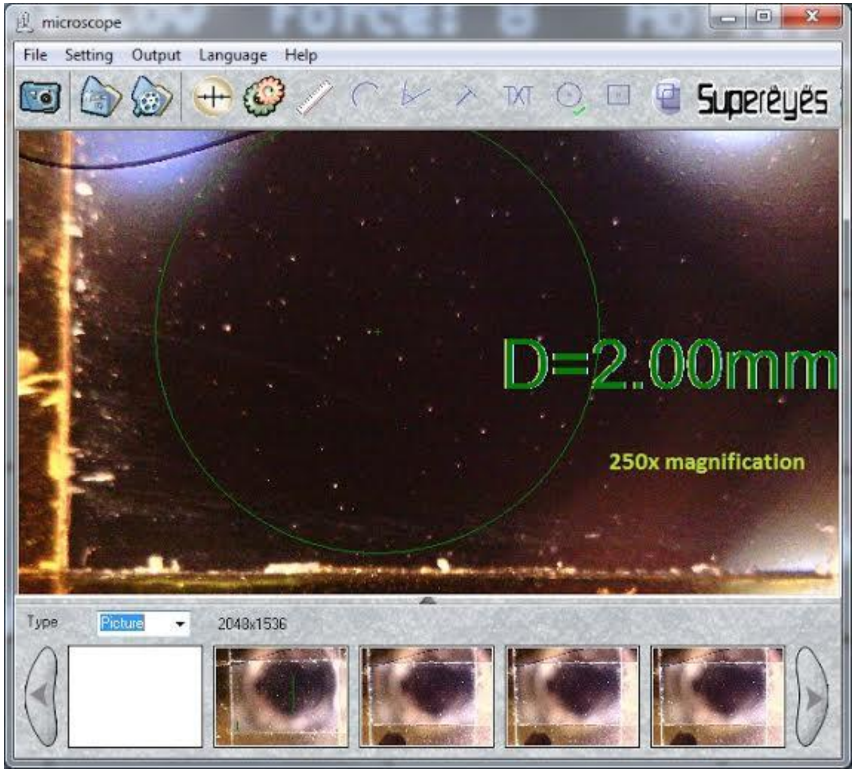
March 2016 coating after CMP polish (image 250-microns across)



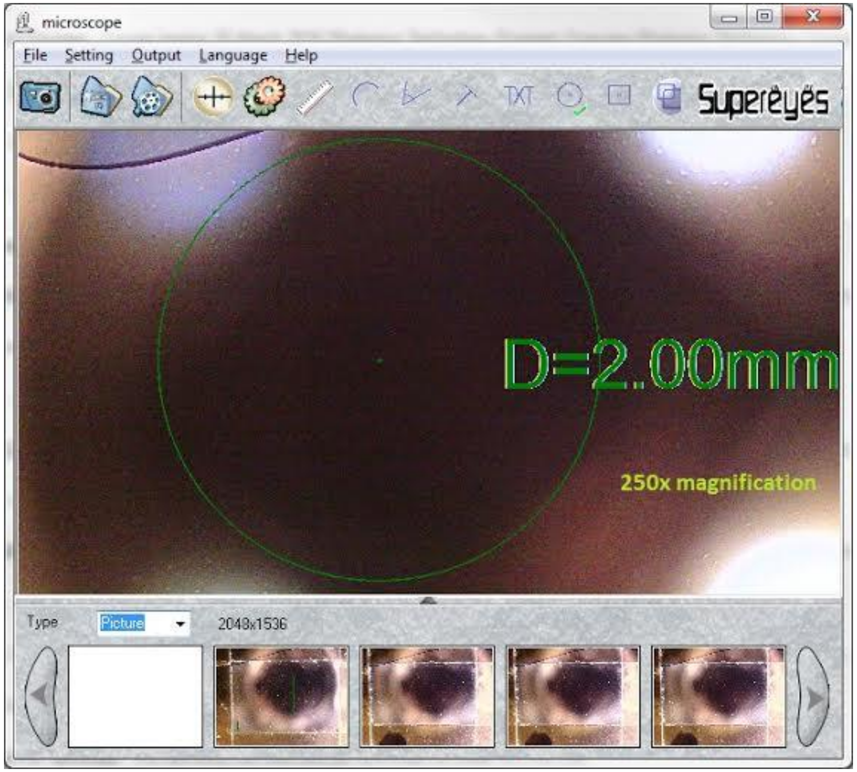


Defects before and after CMP polishing

Before polish

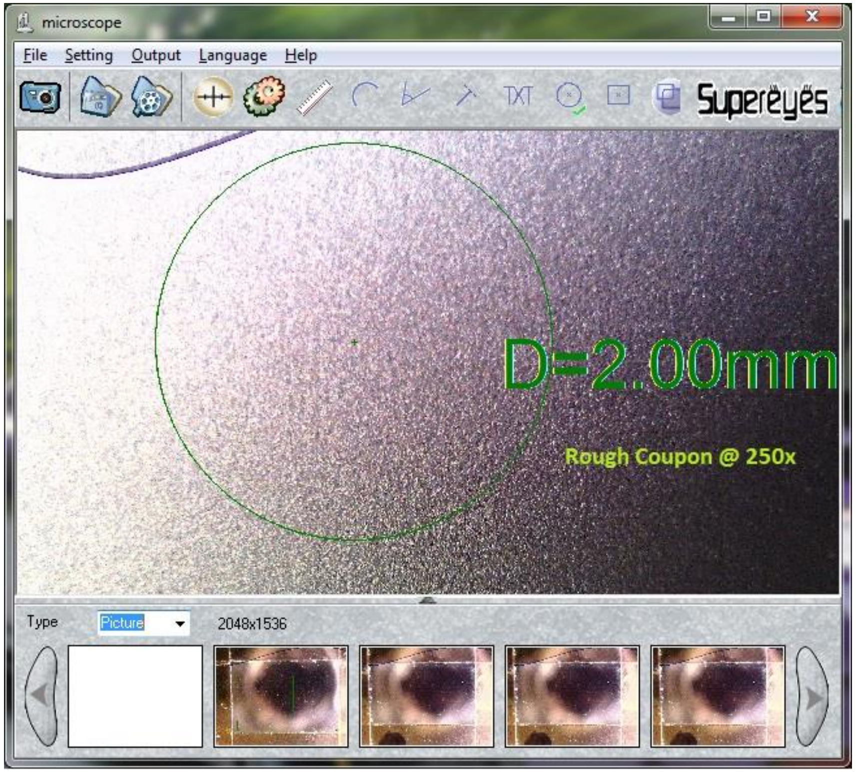


After polish

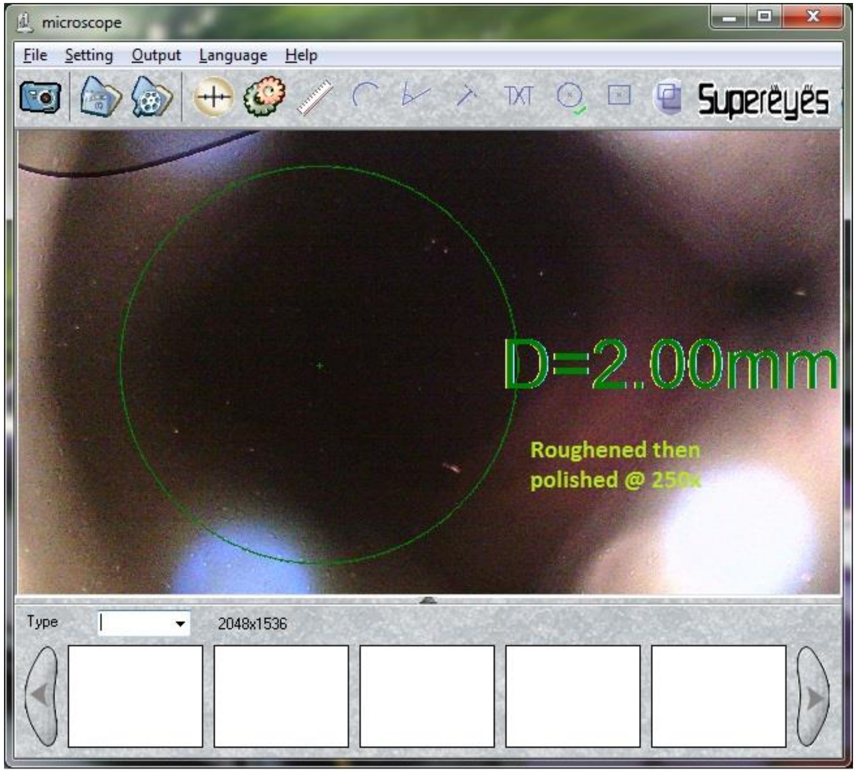


Micro-roughened surface

Ra = 0.45 microns



After polish < 2 angstroms RMS



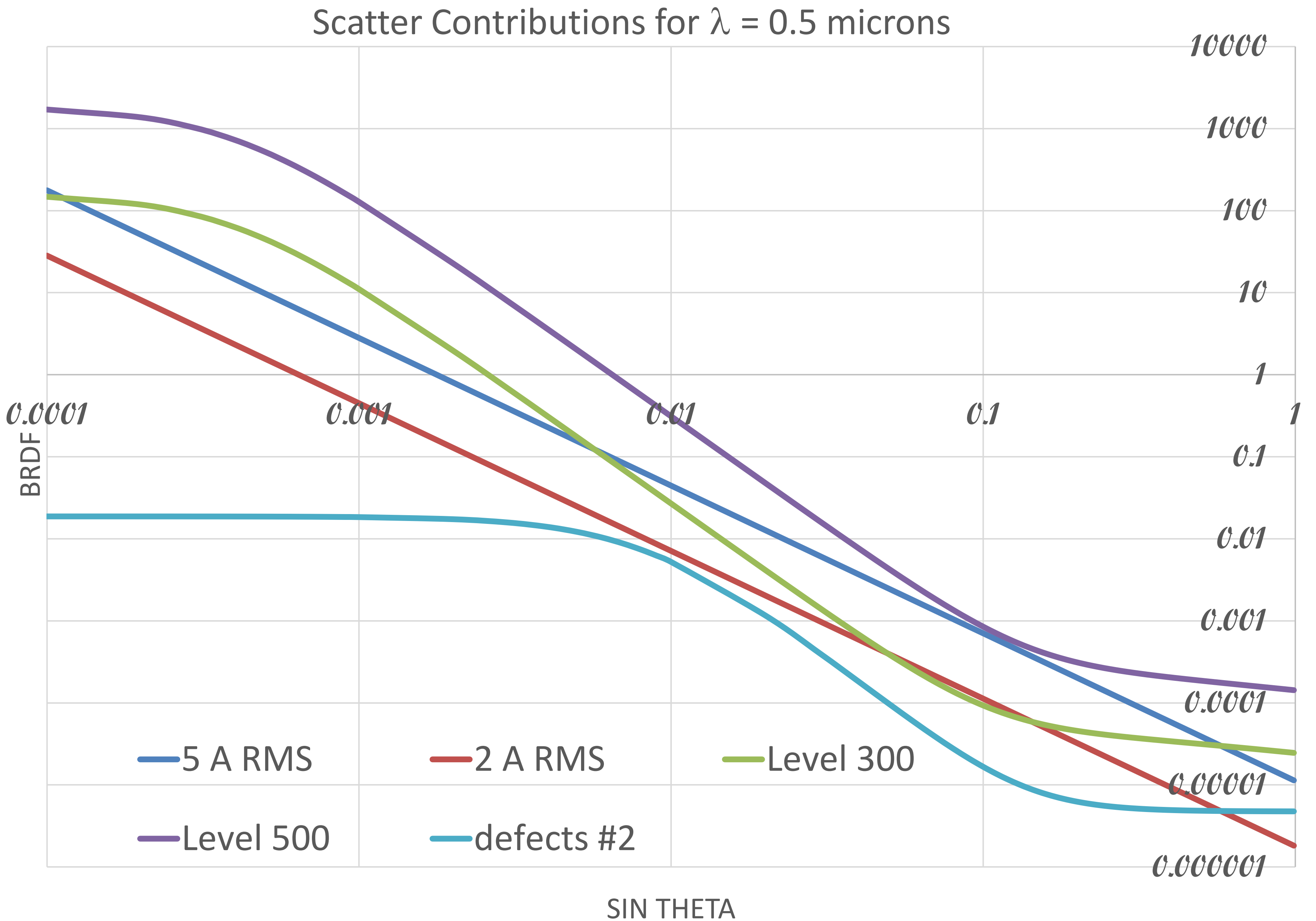
Scratch-dig requirement

- For 60/40 spec, max dig = 400-μm
- Permitted 1 max dig per 20 mm diameter circle
- In addition, smaller digs are permitted, provided the sum of the diameters of smaller digs shall not exceed 800-μm
- Therefore, if each of the smaller digs is 20-μm, up to 127,400 per square meter are allowed, plus 3,185, 400-μm digs!
- Cladding defects quantified 47,500 per square meter (20-microns or less)

Cleanliness level definition

cleanliness level	particle size (microns)	max # of particles per sq. meter
300	25	74500
	50	10200
	100	950
	250	22
	300	10
500	50	118000
	100	10900
	250	263
	500	10

	particle size (microns)	max # of particles per sq. meters
Cleanliness level 300	25	74,500
	50	10,200
	100	950
	250	22
	300	10
Cleanliness level 500	50	118,000
	100	10,900
	250	263
	500	10
ZeCoat #2 defects	20	47,775
60/40 scratch dig	20	127,400
	400	3,185



Scatter Contributions for λ = 0.5 microns
10000
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0001
0.001
0.01
0.1
1
BRDF
SIN THETA
5 A RMS
2 A RMS
Level 300
Level 500
defects #2

Types of polishing methods

- Chemical mechanical polishing (CMP)
  - Combination of chemical etching and mechanical polishing via a slurry of material
  - Works on flats, used for semiconductor processing
- Conventional polishing (lap tool)
- Magnetorheological finishing (MFR)
  - MR fluid's shape and stiffness are magnetically manipulated. The optic's final surface form are predicted through the use of computer algorithms.

Commercialization/NASA infusion

- Semplastics Phase II SBIR
- Fantom Materials

Follow-on cladding development

- Ion gun servicing
  - Currently limited to ~ 8 hours of run-time @ 80-A/sec
  - Solution – Hollowed cathode neutralization (greater than hundred hours runtime without service)
- More work needed to understand how small defects are formed so they may be minimized
- More work is needed to understand the polishability of ZeCoat's Si cladding as it relates to RFM
- Extend the technology to other materials like Ge and SiO

Conclusions

- ZeCoat has demonstrated a low-stress, low-temperature silicon cladding process
- Need to reduce defect density to use MFR polishing process
- Defects may not be a problem for primary mirrors positioned away from the image plane but they are a problem for applications like high-energy lasers, or secondary/tertiary mirrors, where the light is highly concentrated
- Need help defining “real” requirements for future telescope specifications, particularly acceptable defect size and density, and scatter requirements as a function of wavelength
- ZeCoat’s largest processing chamber can coat mirrors up to 1.15-meters in diameter and the process is scaleable to larger mirrors, limited only by the size of the vacuum chamber

Questions?