Differential Deposition Figure Correction for X-ray Optics

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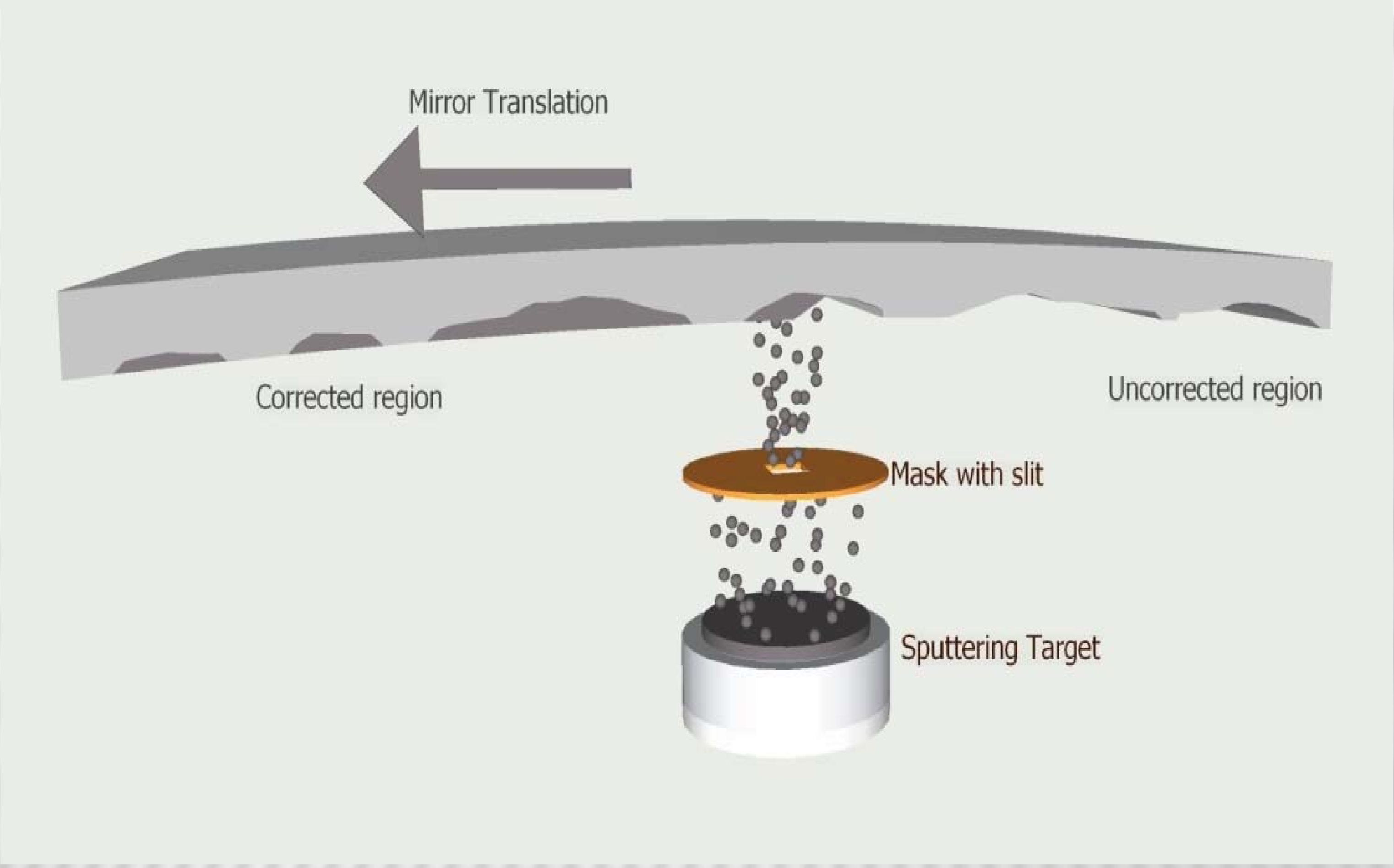
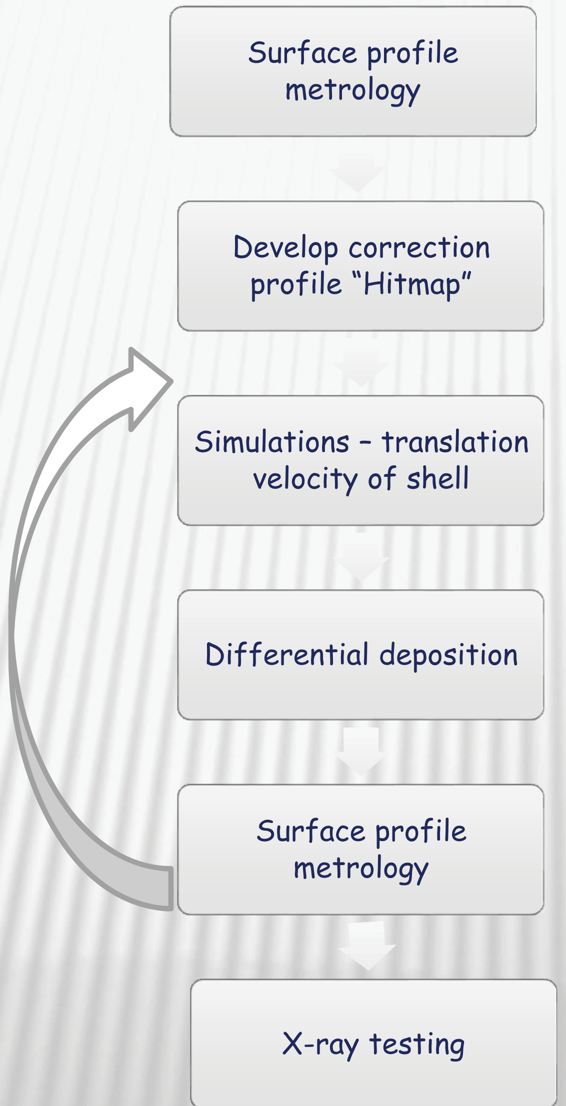
Differential Deposition

- ***What***
  - Differential deposition is a technique for correcting figure errors in optics
- ***How***
  - Use physical vapor deposition to selectively deposit material on the mirror surface to smooth out figure imperfections
- ***Why***
  - Can be used on ***any type*** of optic, full-shell or segmented, mounted or unmounted
  - Can be used to correct a wide range of spatial errors. Could be used in conjunction with other techniques… e.g. active optics.
  - Technique has been used by various groups working on synchrotron optics to achieve sub-μradian-level slope errors

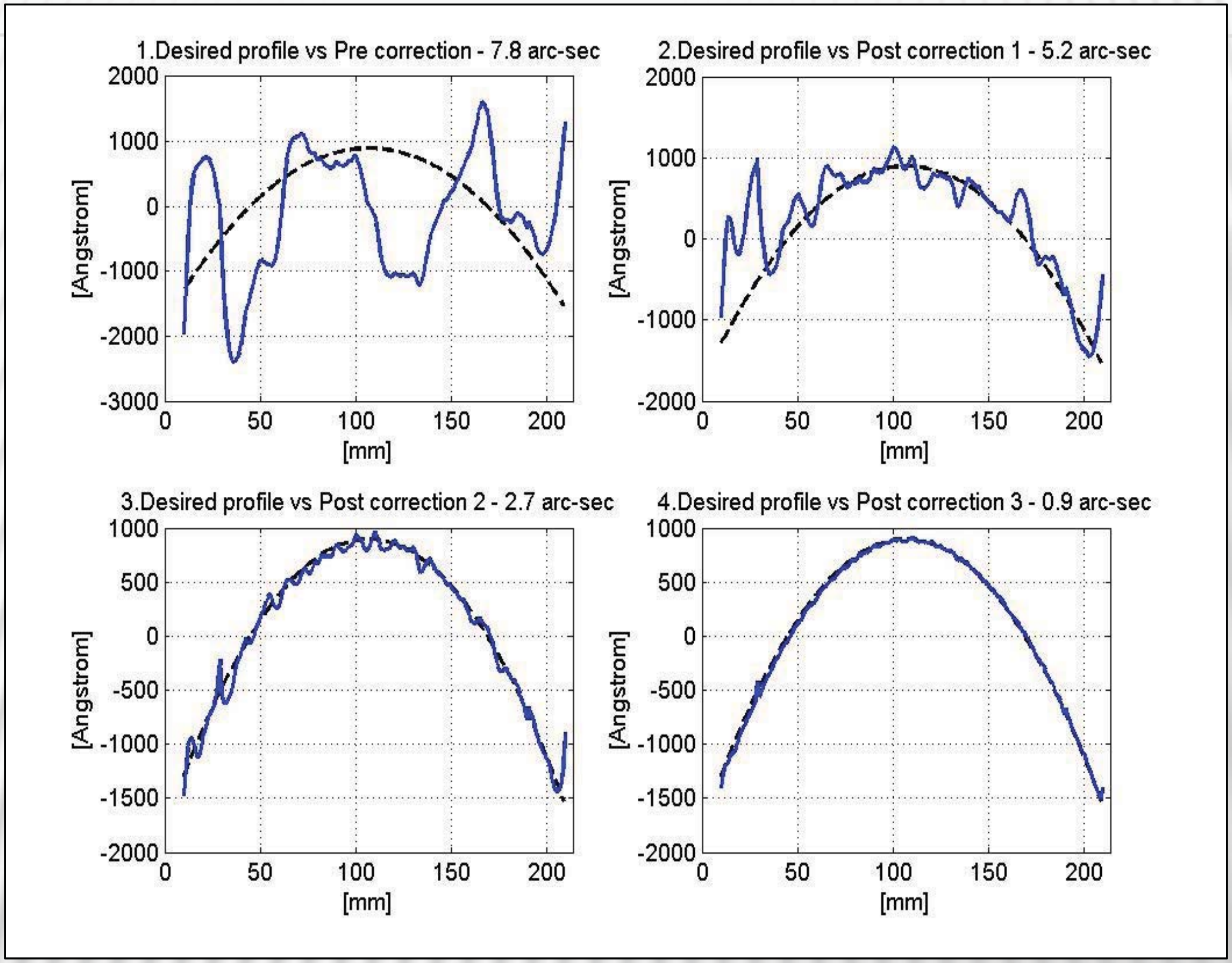
Coating Configuration



Process Sequence - Differential Deposition

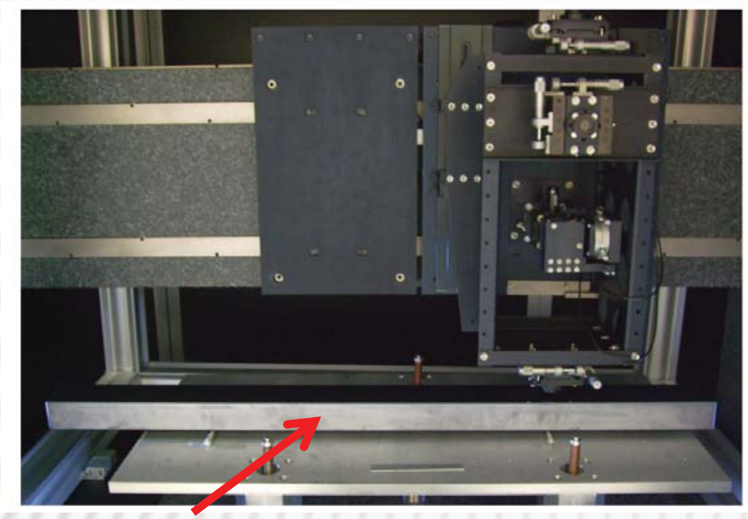


Process Sequence – Differential Deposition



Simulated correction sequence showing parabolic axial figure profile before (top left) and after 3 stages of correction using a beam of FWHM = 14mm, 5.2 mm and 1.7 mm respectively. The dotted line gives the desired figure and the solid line gives the figure obtained at each stage. Overall, resolution improved from 7.8 arcsec to 0.9 arcsec HEW (2 bounce equivalent).

Heritage-Technique Used for Synchrotron Optics



Optic undergoing metrology

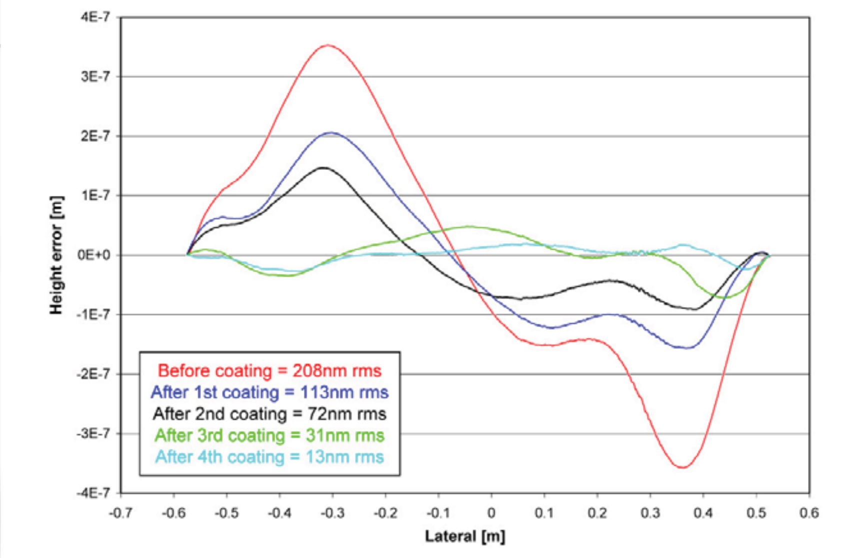
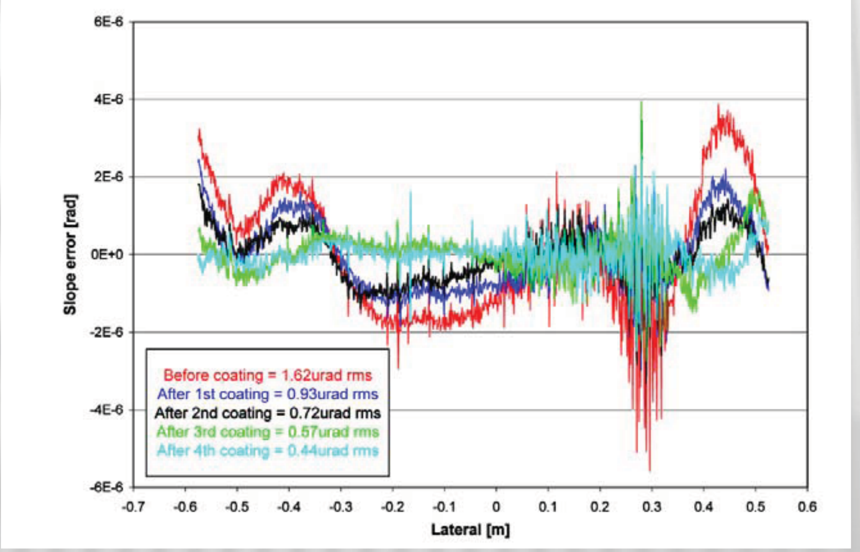


Figure errors after differential coating runs



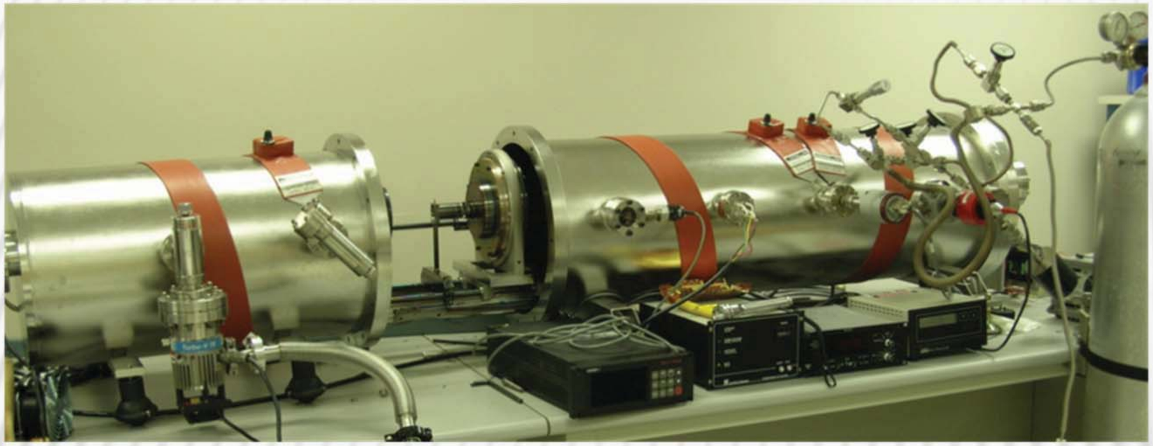
Slope errors after differential coating runs

From:
A preferential coating technique for fabricating large, high quality optics

S.G. Alcock, S. Cockerton,

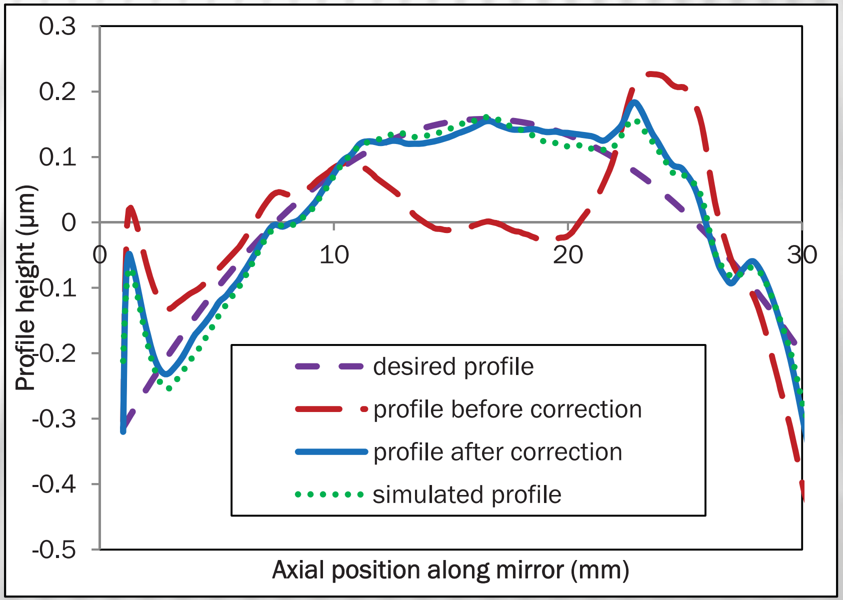
NIM A 616, 2010

Proof of concept on miniature optics



Modify an old coating chamber

Miniature medical optics

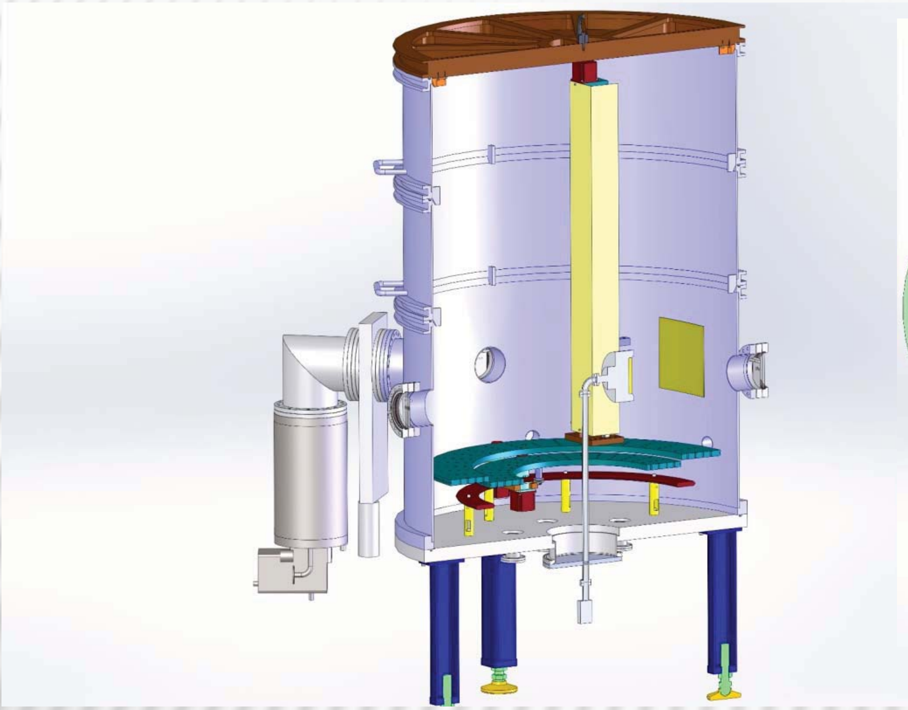


Slope improvement from 12 to 7 arcsec rms

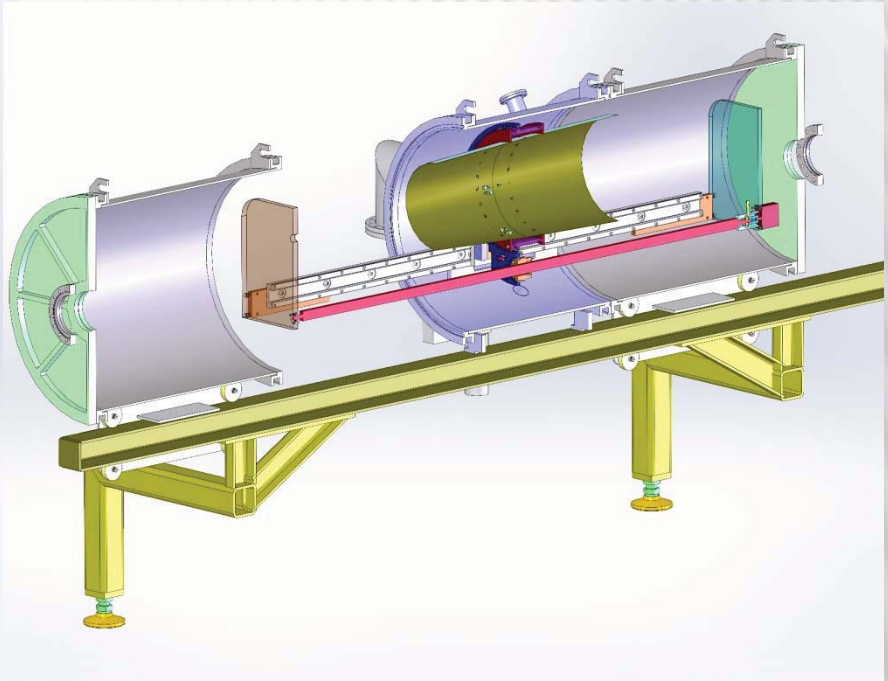
Possible Practical Limitations We Are Addressing

- *Variation of sputtered beam profile along the length of mirror – particularly for short focal length mirrors – Model and correct*
- *Deviation in the simulated sputtered beam profile from actual profile, beam non-uniformities, etc. – Quantify and correct*
- *Positional inaccuracy of the slit with respect to mirror – Model effects to derive requirements*
- *Metrology uncertainty – Upgrade metrology system*
- *Stress effects – Quantify and control stress*

Coating Systems (DC magnetron)



Vertical chamber for segmented optics



Horizontal chamber for 0.25-m-scale full shell optics

Coating Systems

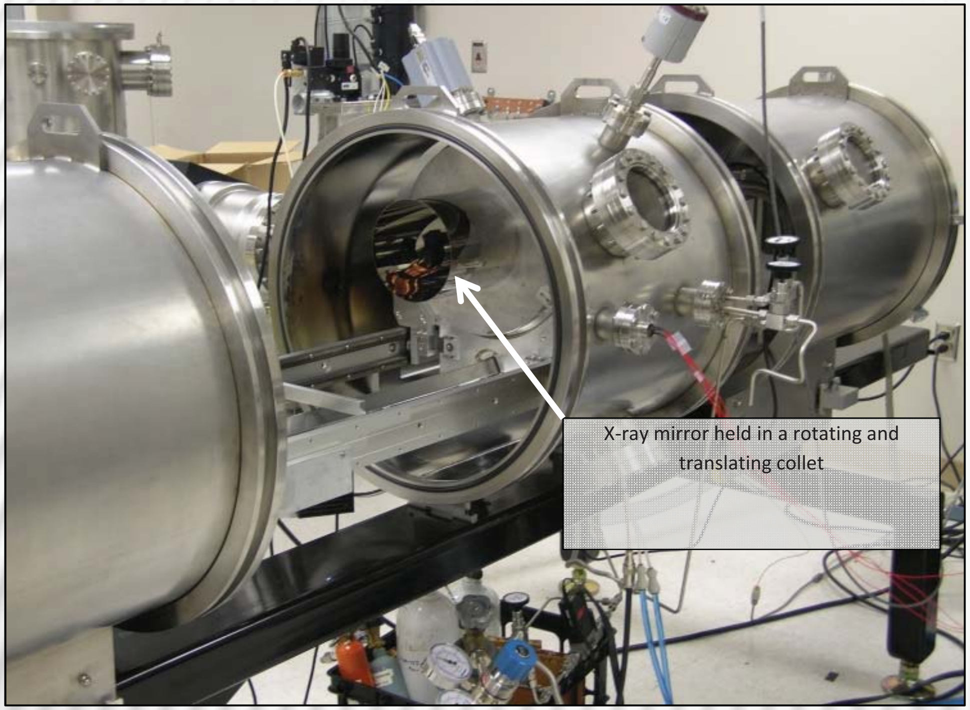


Figure 2: Horizontal differential-deposition chamber

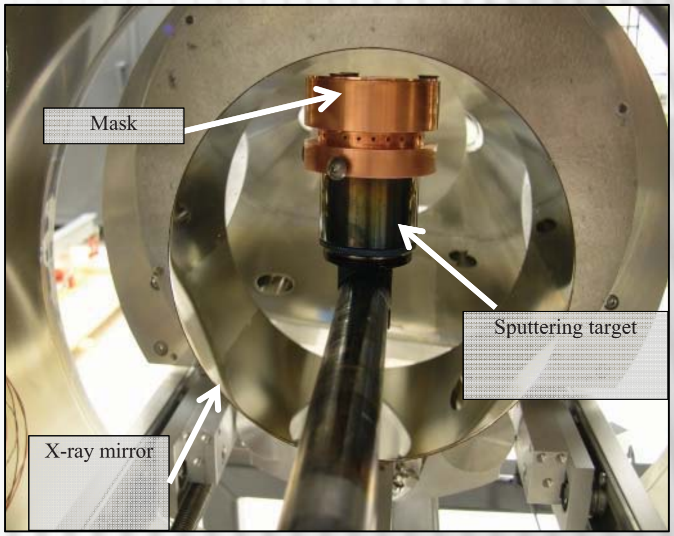
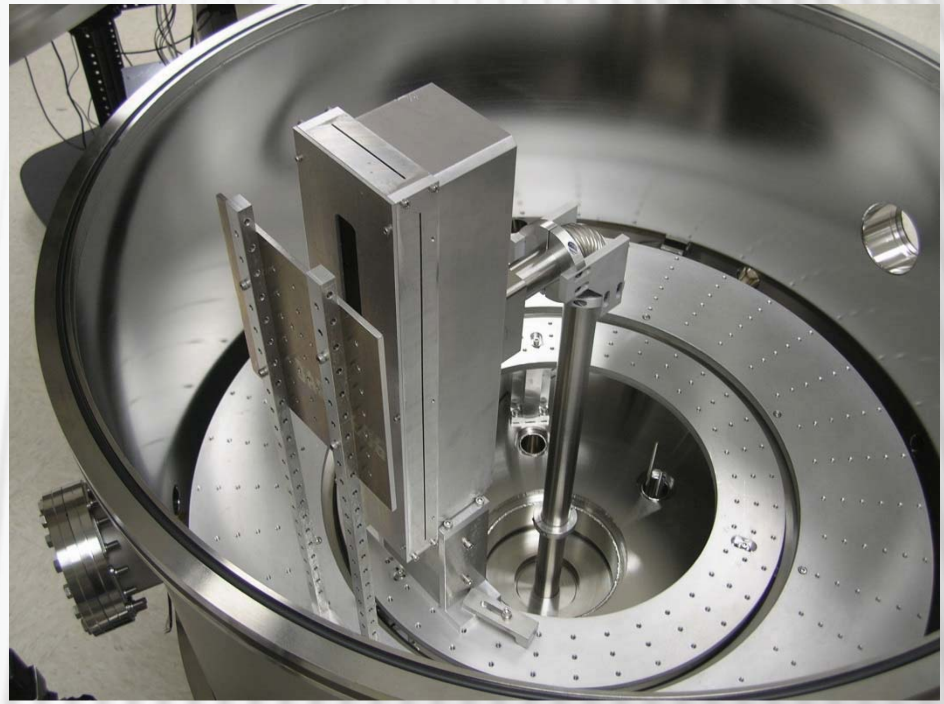


Figure 3: Sputtering head with copper mask positioned inside shell

Coating Systems



Vertical deposition chamber

New Coating Systems – Test Coatings

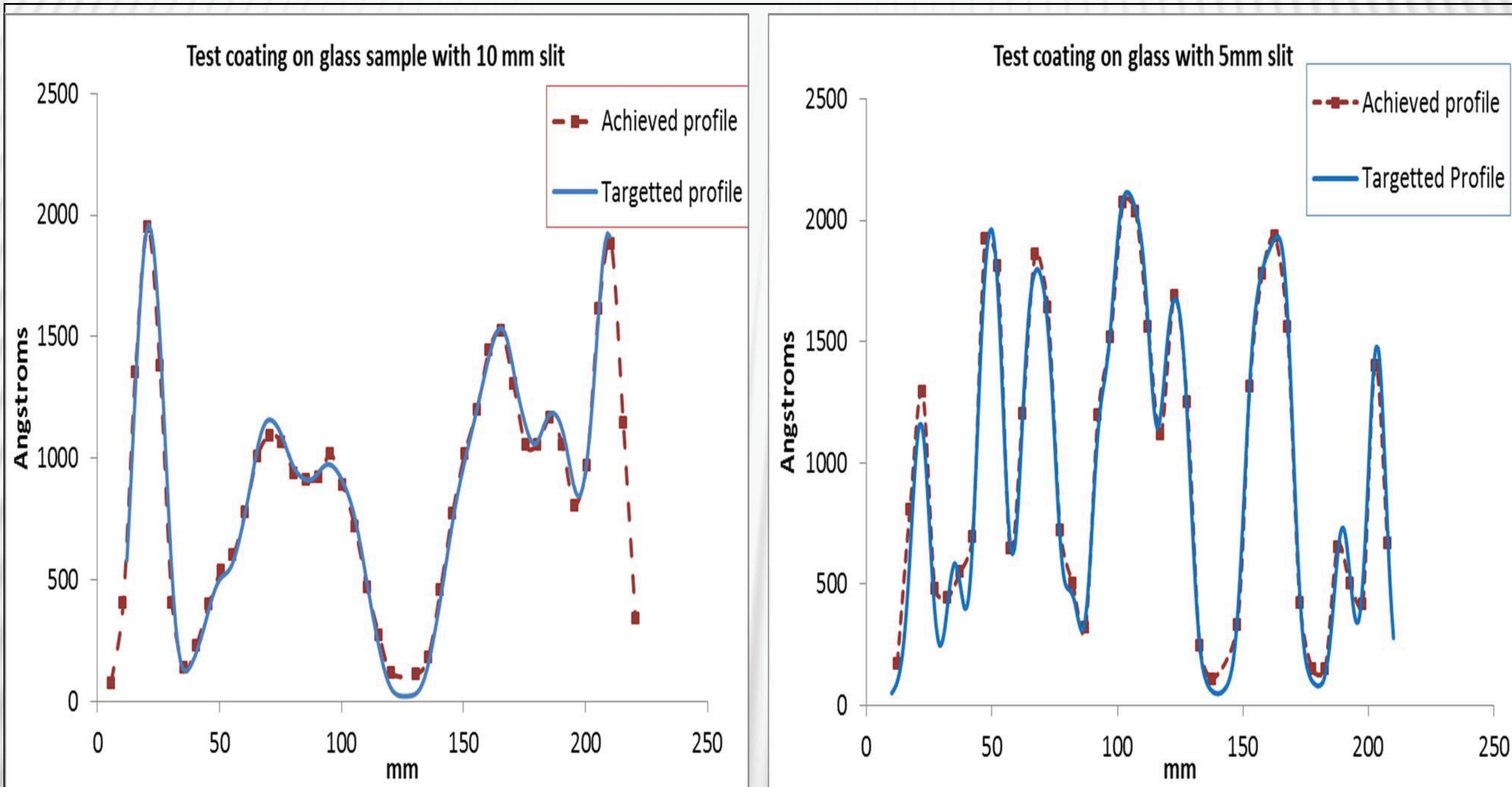
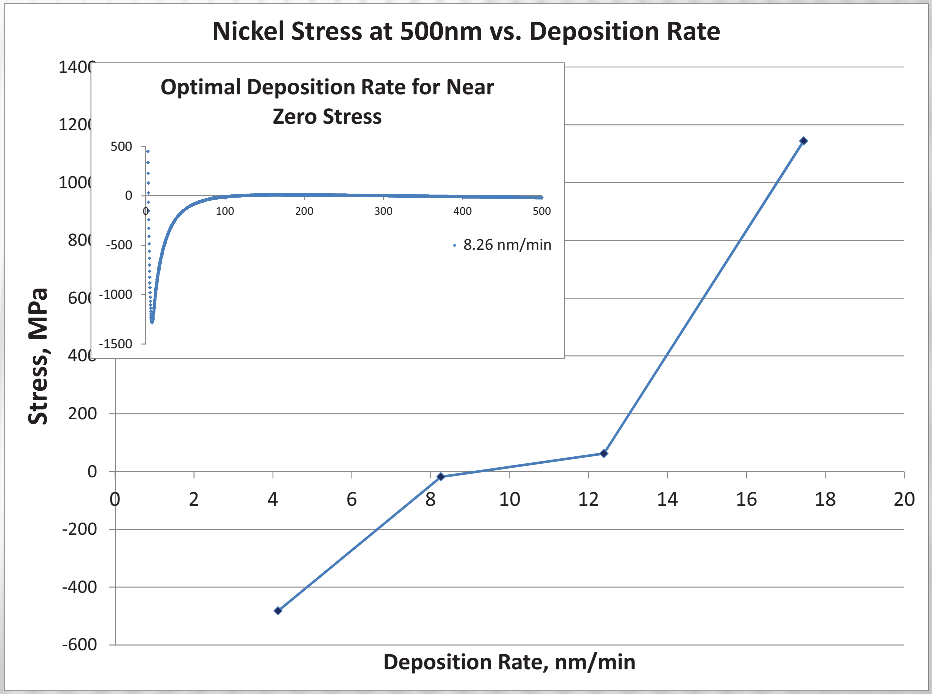


Figure 6: Test coatings on glass samples with 10mm and 5mm slits

Coating Stress Measurement System

Simulations show that for full shell optic need < 10MPa stress to get < 1 arcsec optic. Set up dedicated system to characterize coating stresses.

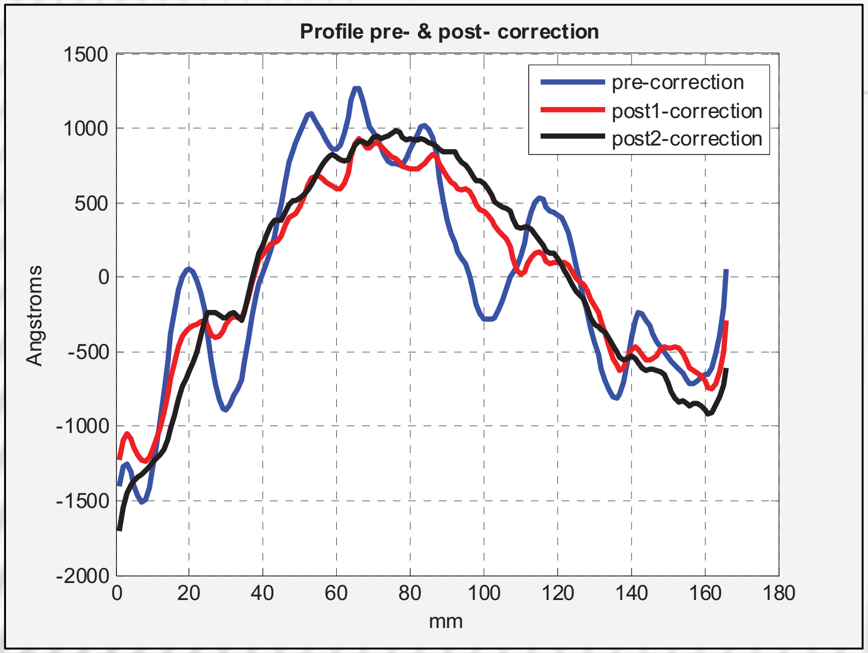


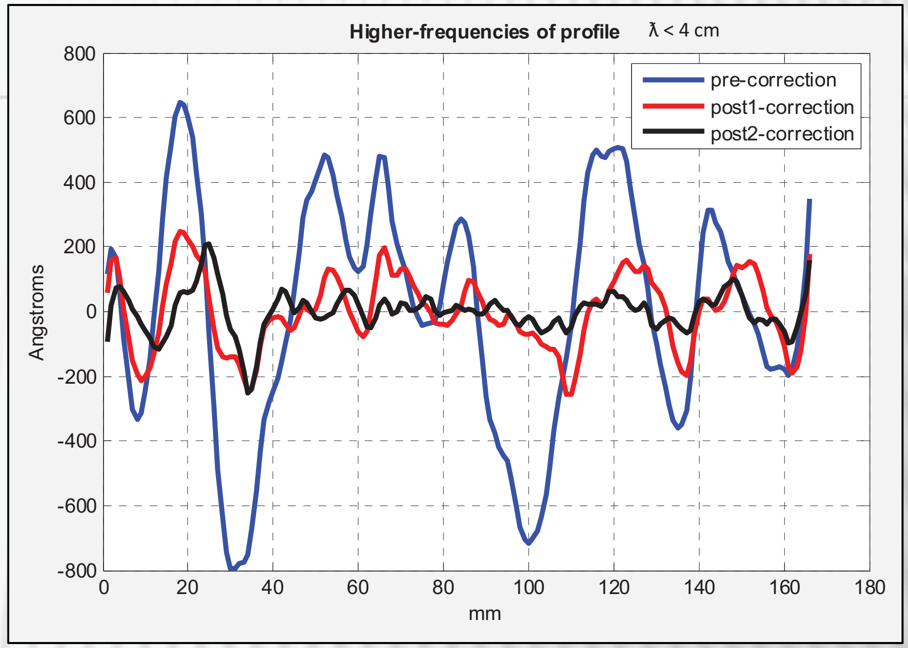
Preliminary measurements showing coating stress versus deposition rate at fixed gas pressure. Inset shows stress versus coating thickness (nm) at fixed deposition rate

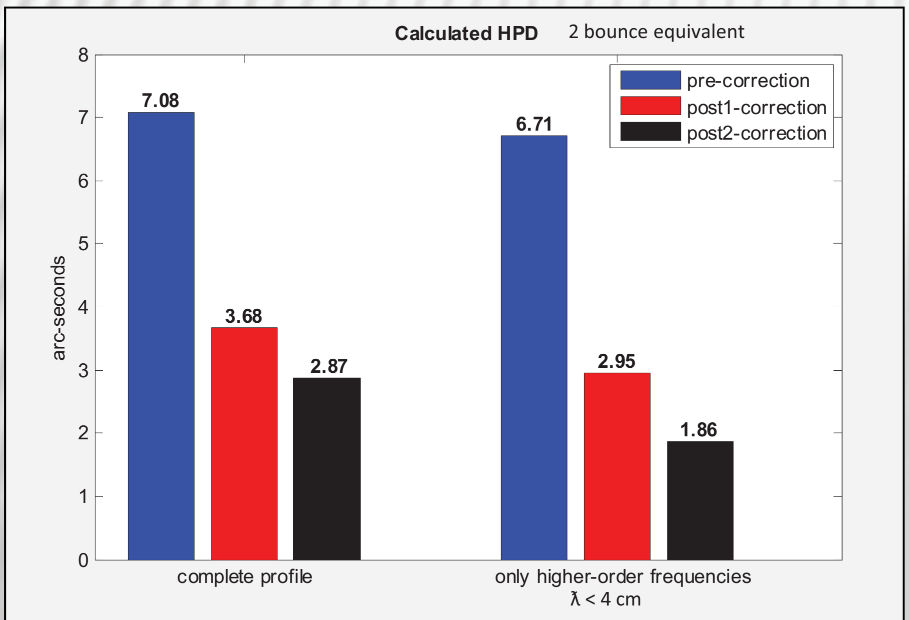
Metrology Upgrade

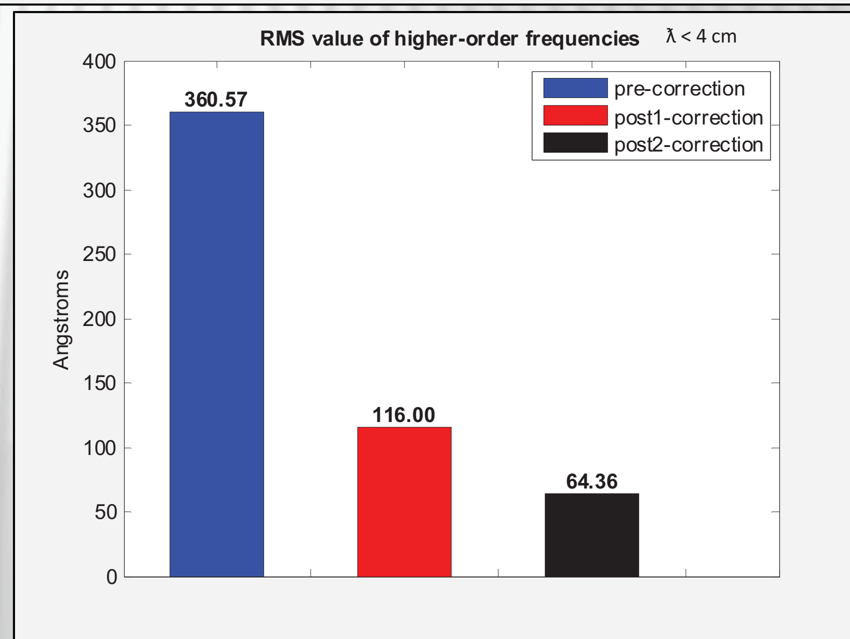
We are upgrading our vertical long-trace profilometer with new computer system and software provided by collaborators at Lawrence Berkeley Laboratory. In progress.

Test coating run # 1: horizontal chamber, 150 mm diameter shell
P-end, pre- and post- two stages of correction

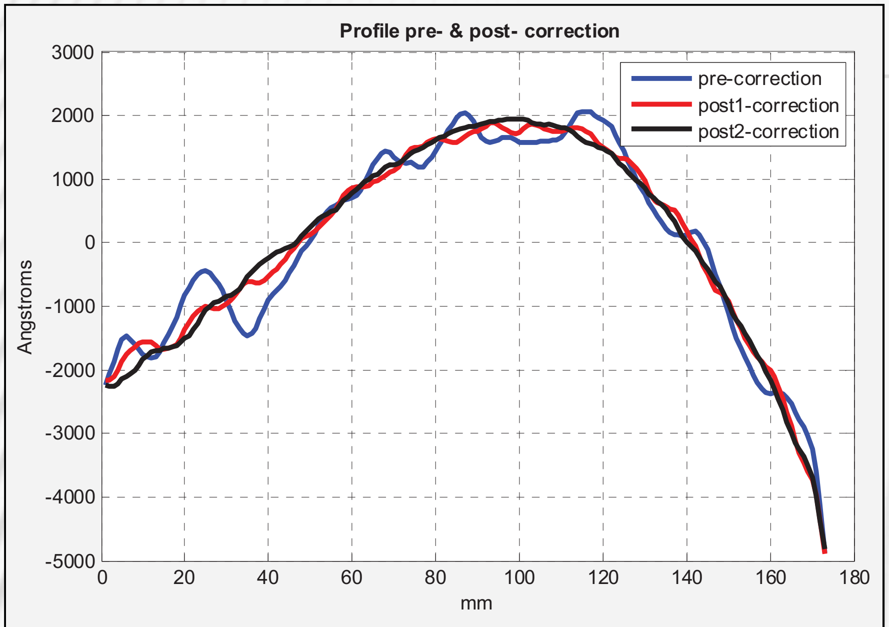


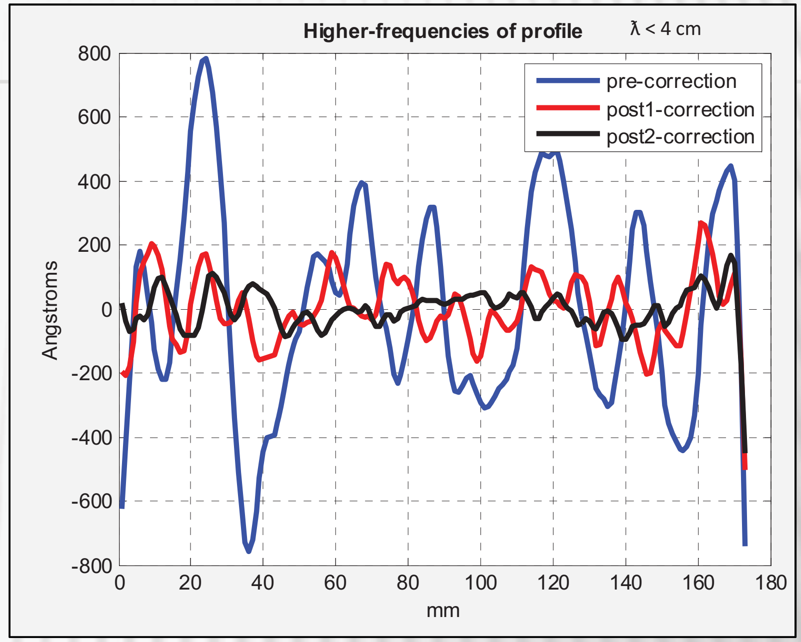


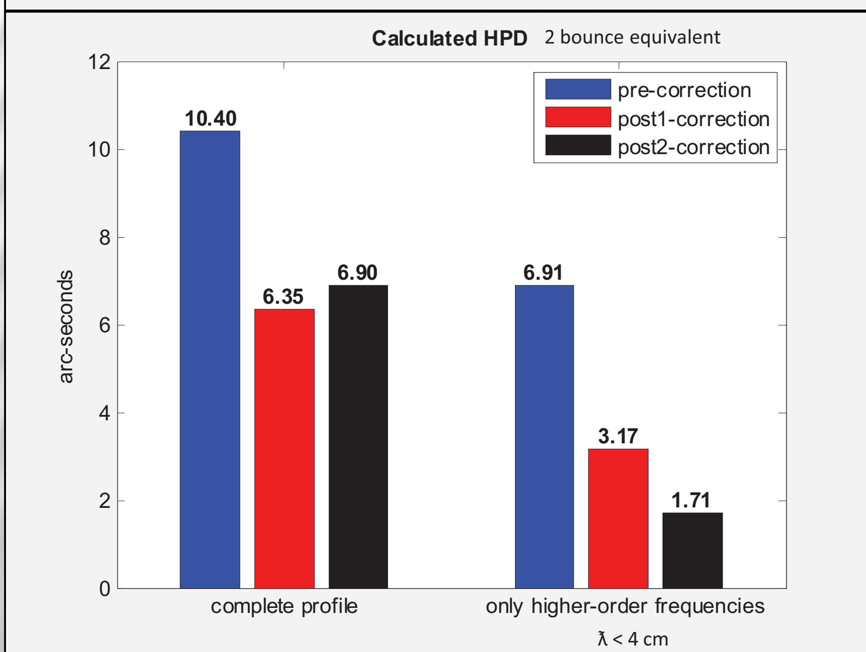


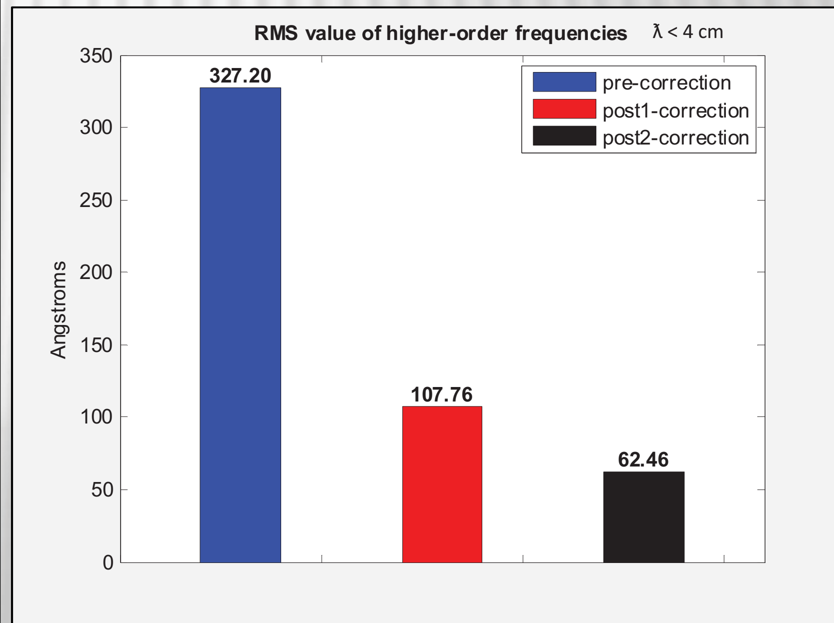


Test coating run # 2: horizontal chamber, 150 mm diameter shell
P-end, pre- and post- 2 stages of correction









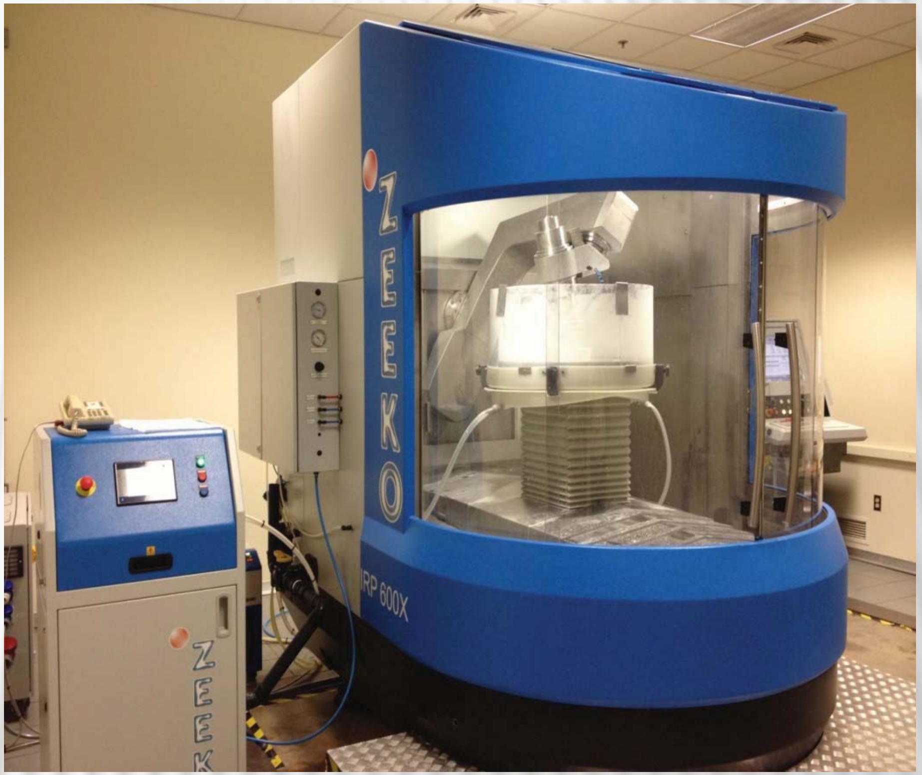
Differential Deposition – Top Challenges

• Metrology on the inside of the thin shells is very challenging. For 2 stages of correction need to get reliable and repeatable metrology to 10’s Angstrom. Removing and mounting the thin shells for metrology is a tricky business. In-situ metrology, planned in current APRA proposal, would significantly improve matters.

• Stress remains a concern. We believe we can obtain very-low-stress coatings, but have to demonstrate that the differential deposition chambers can give similar stresses to the stress characterization chamber (as coating conditions change). As an aside it may be possible to use a thin layer of a stressed coating to change the figure instead of filling it in. We are also investigating this.

Full Shell Direct Fabrication

- Lighter-weight Chandra approach to x-ray optics …. preserves the inherent stiffness of full-shell geometry.
- Use new developments in computer-controlled polishing machines to directly fabricate a thin-shell optic
- Goal is to demonstrate 5 arcsec resolution in 2 years, then explore what limits may be possible

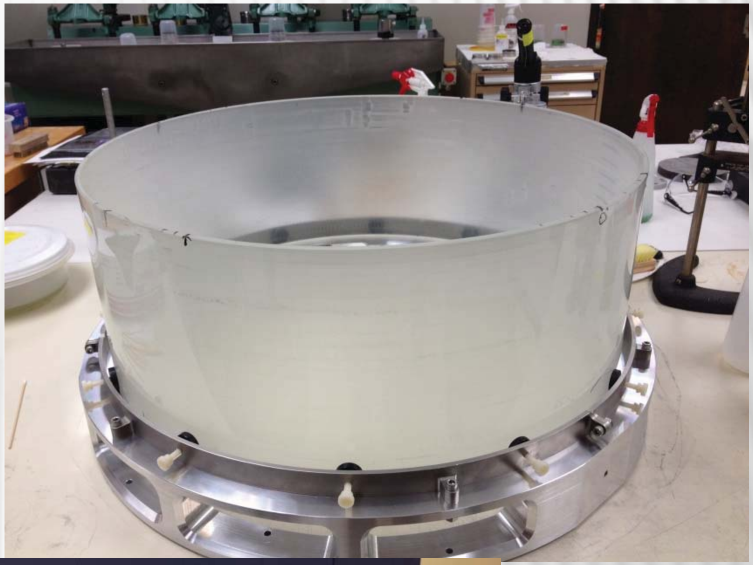


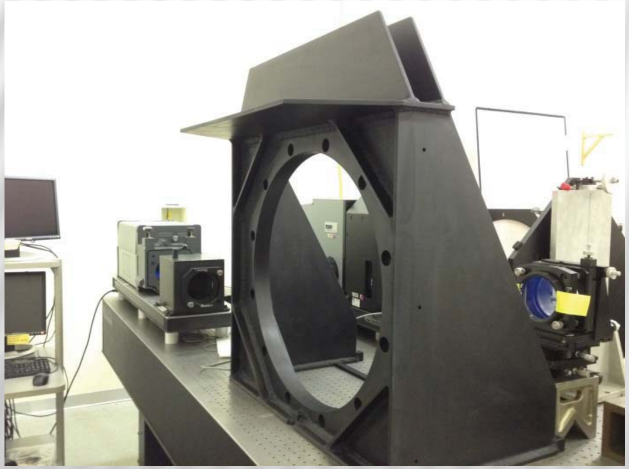
ZEEKO polishing machine at MSFC

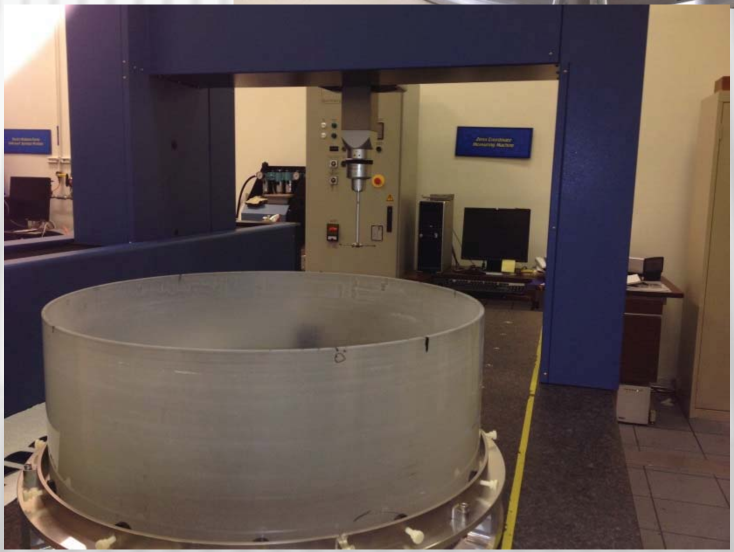
Full-Shell Direct Fabrication

PLAN

- Demonstrate capability with 'thick' (~ 6 mm) shell first
    - Gain experience with ZEEKO machine (in process)
    - Grind glass shell ready for ZEEKO machine 👍
    - Fabricate fixturing for polishing shell 👍
    - Fabricate fixturing for metrology of shell 👍
- Move to thin shells (2-3 mm)
    - Develop polishing fixtures (in process)
    - Develop metrology fixtures (in process)
- Candidate materials
    - Start with glass (pyrex, fused silica)
    - Also investigate Be and AlSi alloys





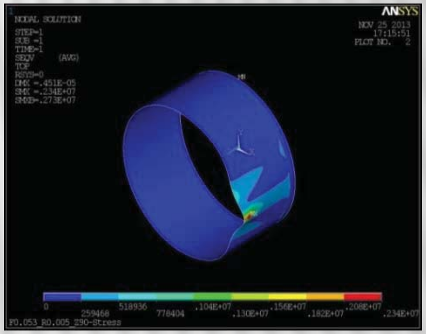


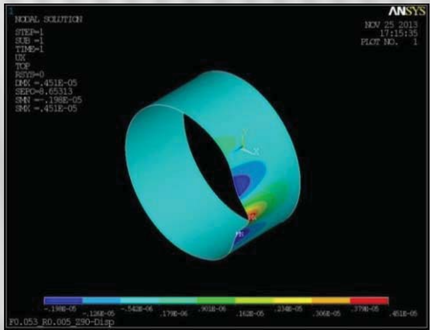
Full Shell Direct Fabrication

Challenge: Supporting glass during fabrication … the glass can easily be broken by polishing stresses

Table below shows results of finite element analysis of a simply-supported glass shell being polished with a bonnet force of 1N (~ 100g). Stress is given for 9 positions along shell length. Working strength of fused silica is just 7 MPa !

Position	Stress 6 mm shell MPa	Displacement 6 mm shell Micron	Stress 2 mm shell MPa	Displacement 2 mm shell Micron
1	1.2	0.02	11	0.3
2	4.4	1.0	25	14
3	3.7	1.7	25	19
4	4.0	2.2	27	24
5	4.5	2.9	31	31
6	4.9	3.5	34	38
7	5.2	4.4	36	48
8	5.4	5.2	37	58
9	6.1	7.5	42	82

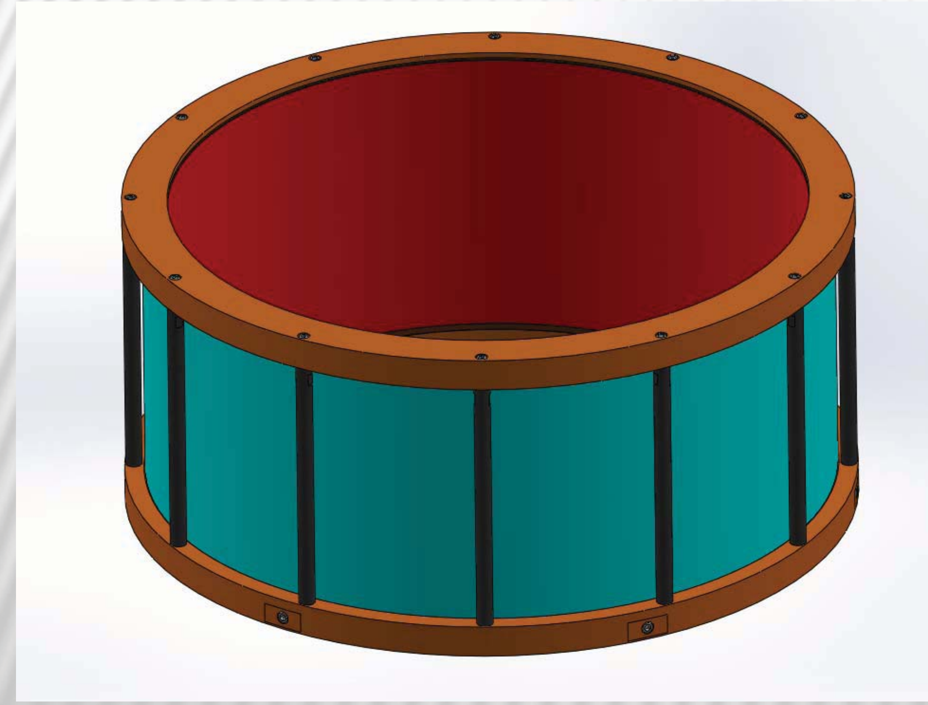


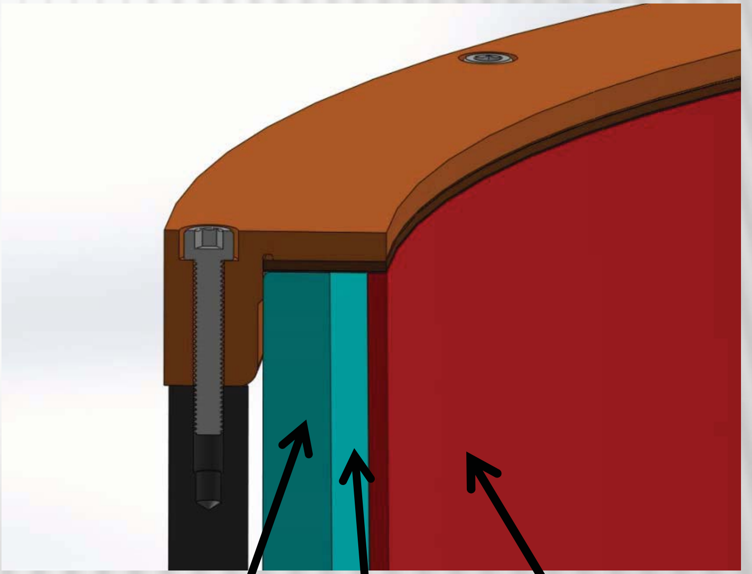


Full Shell Direct Fabrication

Solution: Support glass over whole length during fabrication

Multiple contact points would reduce stress but could lead to print-through. Use a support 'fluid' to restrain thin shell while under fabrication





Backing Material

Gap to fill with support 'fluid'

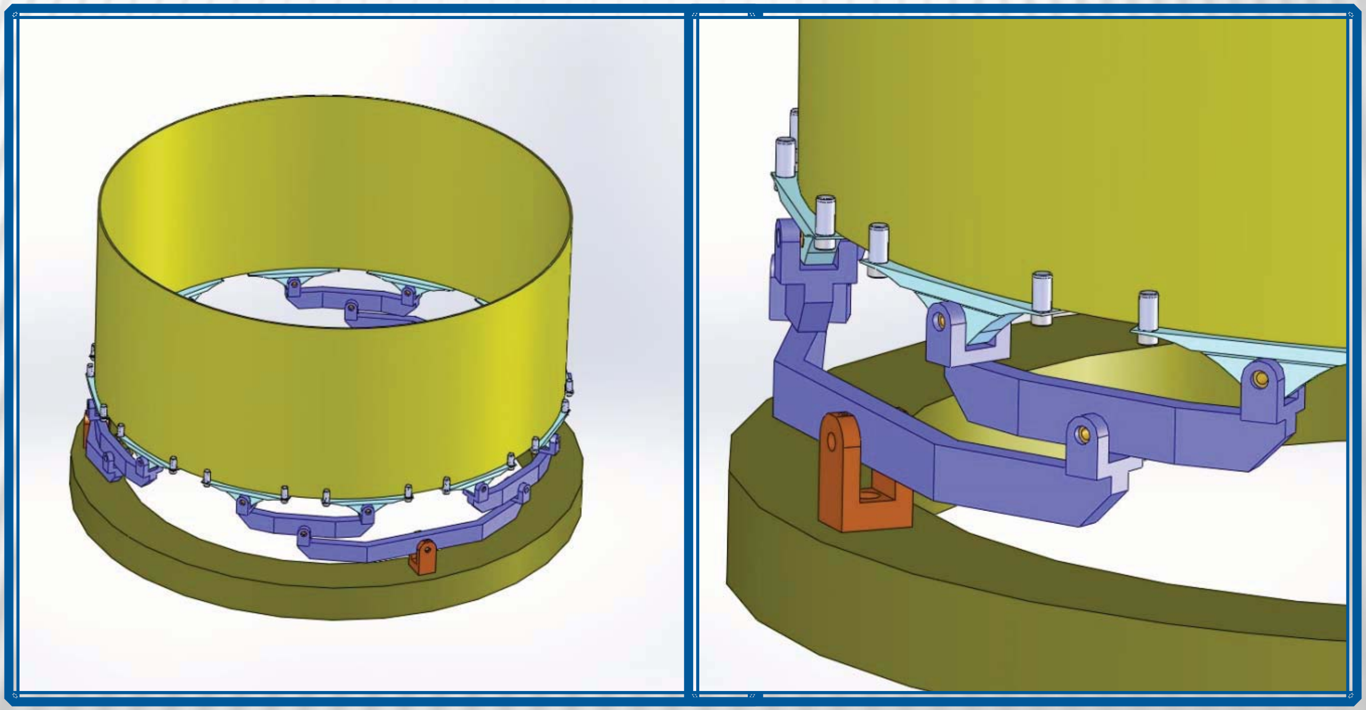
Thin Shell

Full-Shell Direct Fabrication

Challenge: Supporting glass during metrology

Need to know the true figure of the shell. Polishing fixture will distort shell at some level.

Solution: to use a metrology mount that preserves the native shell figure (mount is termed a 'whiffle tree').



Direct Fabrication – Current Status

Thick Shell

- All fixturing has been completed and we are ready to start thick shell fabrication

Thin shell

- Designs for fixturing for metrology and polishing are nearing completion