ZERODUR substrates for application of high-temperature protected-aluminum far ultraviolet coatings

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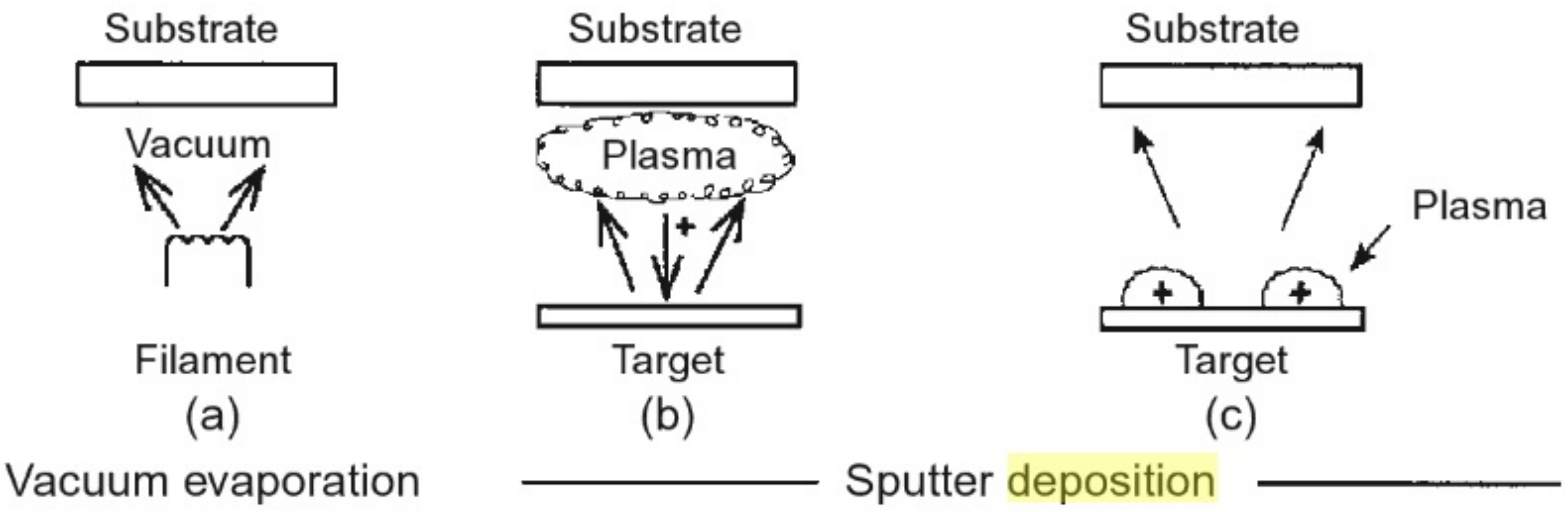
Outline

- Overview & Objectives
- FUV Coating Developments
  - ✓ Coating Processes Overview
  - ✓ High-Temperature Depositions: Solidification vs. Crystallization
  - ✓ Enhanced FUV Reflectance Performance: Al+MgF_2 and Al+LiF
- ZERODUR Heat Treatment Experiments
  - ✓ Process: Experiment Methodology & Sample Details
  - ✓ Interferometry & Data Analysis
  - ✓ Zernike Fit Aberration Results
- Conclusions
- Acknowledgments

Overview and Objectives

- **Summary of goals**
  - ✓ Deposit high performance FUV to FIR optical broadband coatings by a variety of techniques to produce low-absorption metal-fluoride overcoats to protect and enhanced reflectance of Al mirrors.
- **Driver / Need**
  - ✓ High-performance broadband coatings (90-10,000 nm) have been identified as an "Essential Goal" in the technology needs for a future Large-Aperture Ultraviolet-Optical-Infrared Space Telescope (LUVOIR and HabEx).
  - ✓ Low reflectivity and transmission of coatings in the Lyman Ultraviolet (LUV) range of 90-130 nm is one of the biggest constraints on FUV telescope and spectrograph design.
- **Benefits**
  - ✓ The development of broad-band reflectors based on Al with increased performance in the FUV spectral range will be an enabling technology for an instrumentation platform for astrophysics and optical exoplanet sciences with a shared telescope providing high throughput and signal-to-noise ratio (SNR) over a broad spectral range.

Optical Coating Deposition Processes



Sputtering

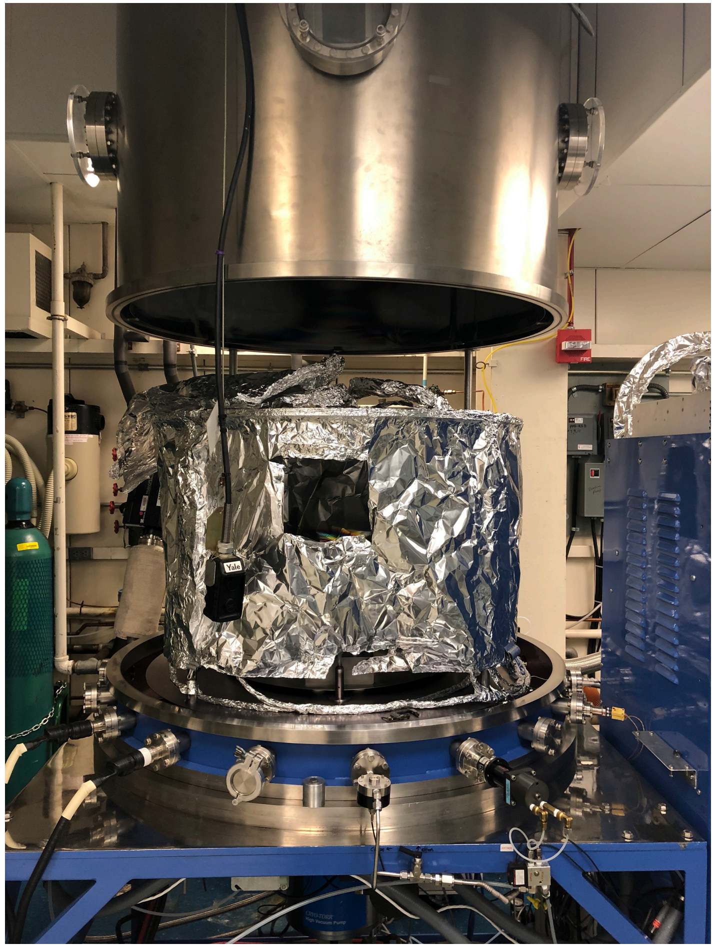
- Non-thermal evaporation process
- Atoms from a target are ejected by momentum transfer from energetic atom-size particles
- Particles are energized by an ion gun
- Deposition rate are much lower than PVD 1-5 Å/Sec.

Physical Vapor Deposition (PVD)

- Material is heated until it reaches vapor form
- Material is deposited on the substrate where it condenses
- Typical deposition rates are 10-160 Å/Sec.

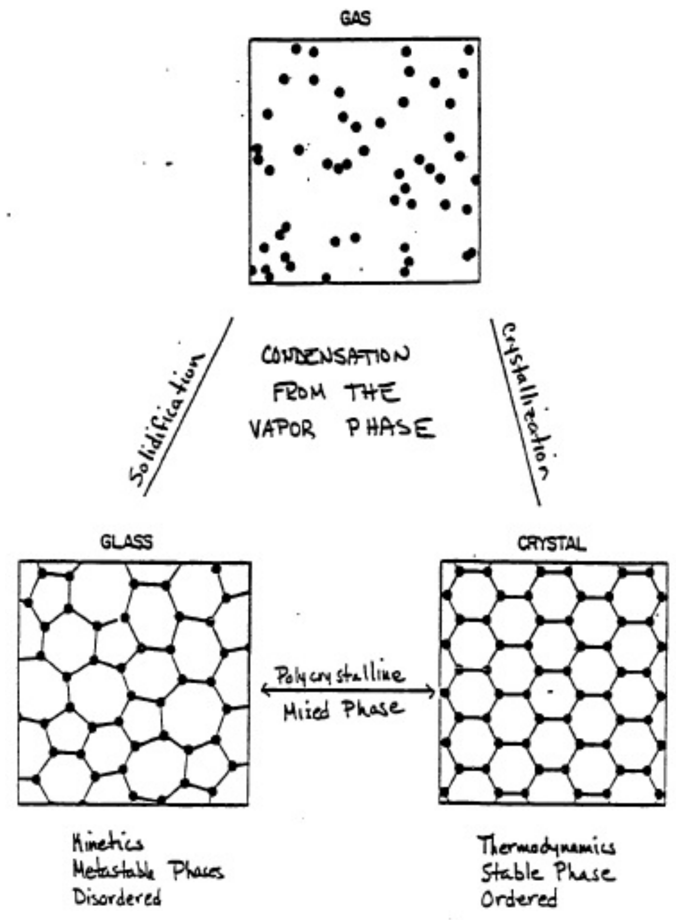
Coating Chambers

ZeCoat's 2.4-m diameter coating chamber with a 1.3-m diameter 900-lb mirror after silver coating

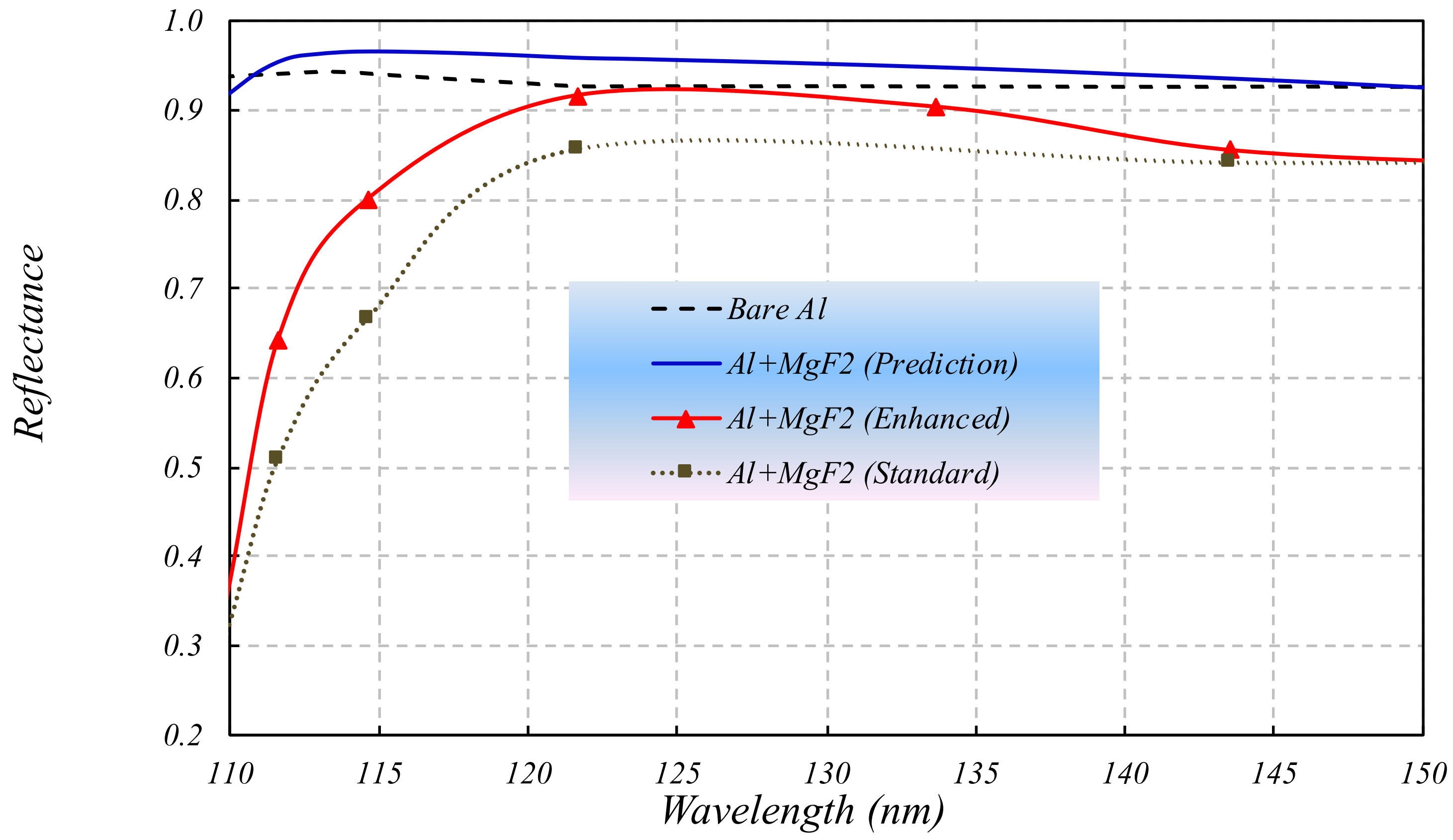


One meter coating chamber at the Goddard Space Flight Center

Solidification vs. Crystallization

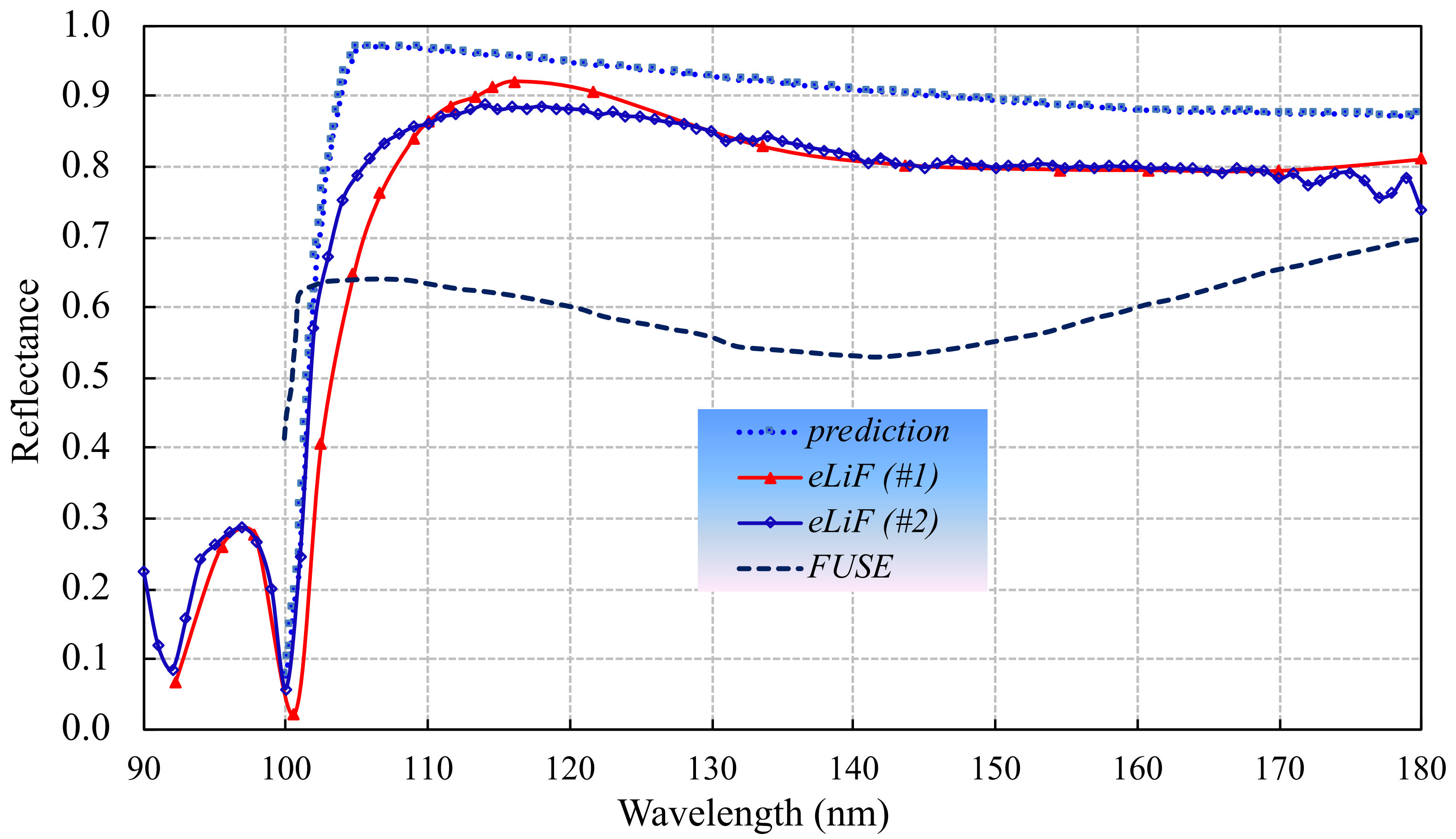


Evaporated Al+MgF_2 Mirror Performance



- Measured reflectance of Al+MgF_2 (Al: 50.0 nm; MgF_2: 25.0nm)
- The black (dash) and blue (solid) lines are predictions for bare Al and aluminum with 2 nm of MgF_2 overcoat respectively
- Enhanced performance is obtained by heating (~220 °C) substrate during MgF_2 deposition in comparison to "standard" process
- Although reflectance is > 80% even at 115.0 nm there is still a big discrepancy when compared to the prediction (due to residual absorption in the MgF_2 film)

Optimization Al+LiF (eLiF) Hot Coatings



- Measured reflectance of two enhanced Al+LiF (eLIF) samples
- The blue (dash) line is a predictions for Al with a 2 nm of LiF overcoat.
- Enhanced performance is obtained by heating (~220 °C) substrate during LiF deposition in comparison to results for mirror coatings in the FUSE project
- Although reflectance is > 80% even at 105.0 nm there is still a big discrepancy when compared to the prediction (due to residual absorption in the LiF film)

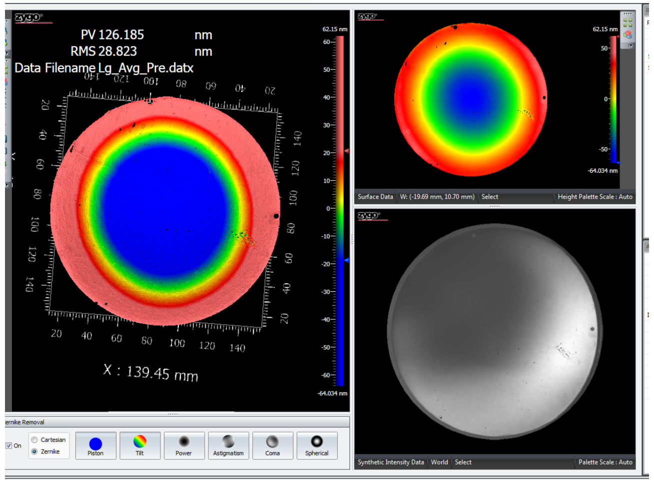
ZERODUR Heat Treatment Experiment

Process:

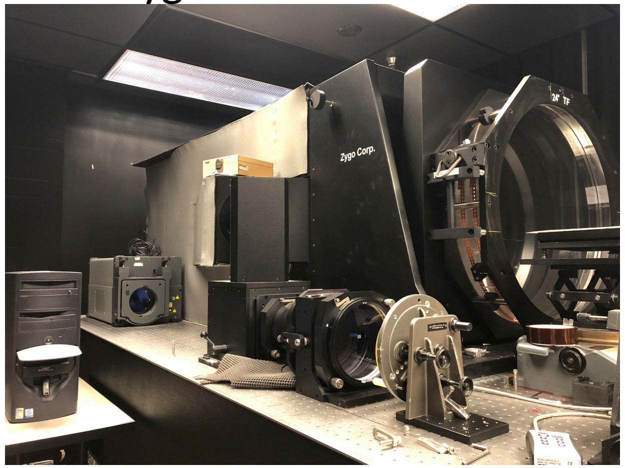
- Preliminary measurements are completed on a Zygo interferometer
- After preliminary measurements, the samples are heat treated
- Return to Zygo and measure again
- Analyze data using Mx (newer Zygo interferometry software, on a different computer)

Process

Pre-Treat Measurement



Zygo Interferometer



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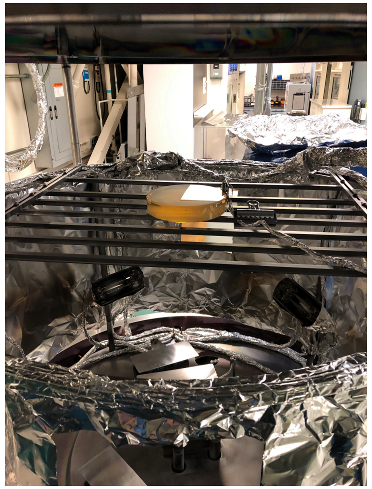
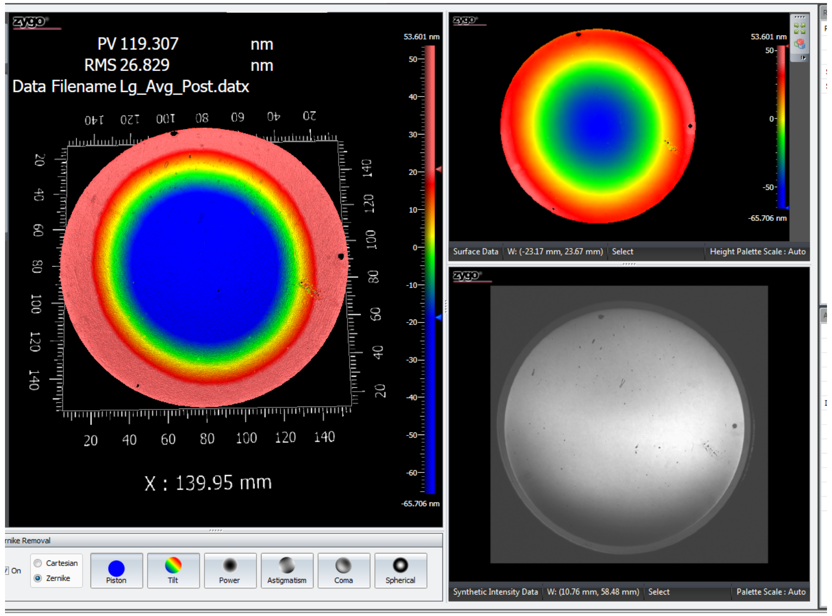
Coatings Chamber



Post-Treat Measurement

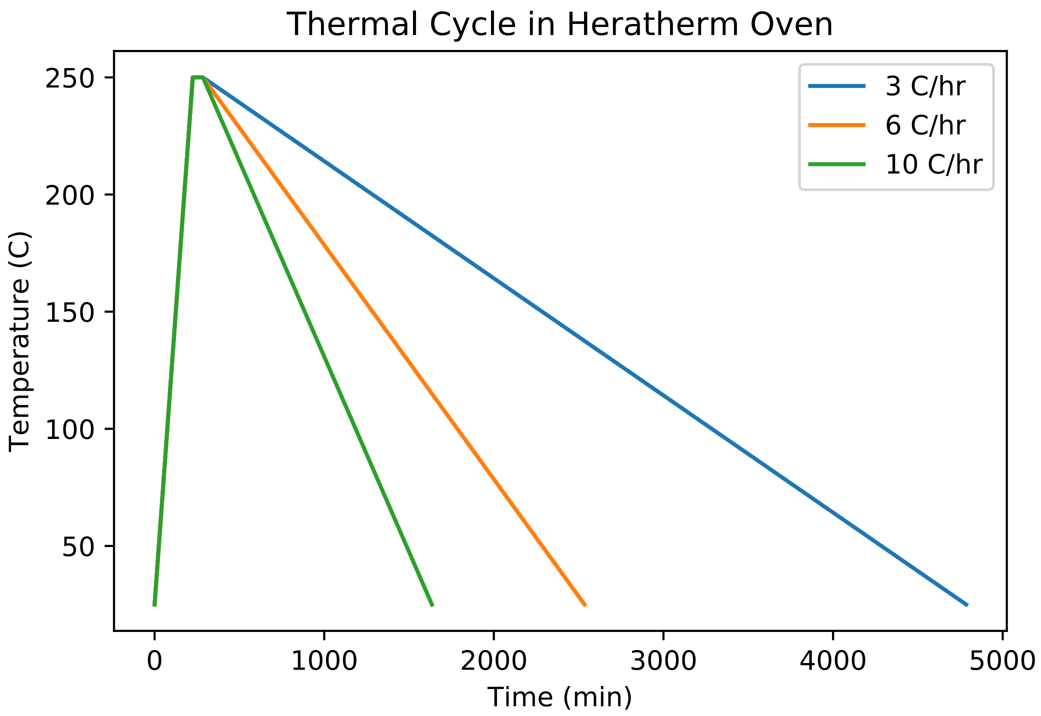


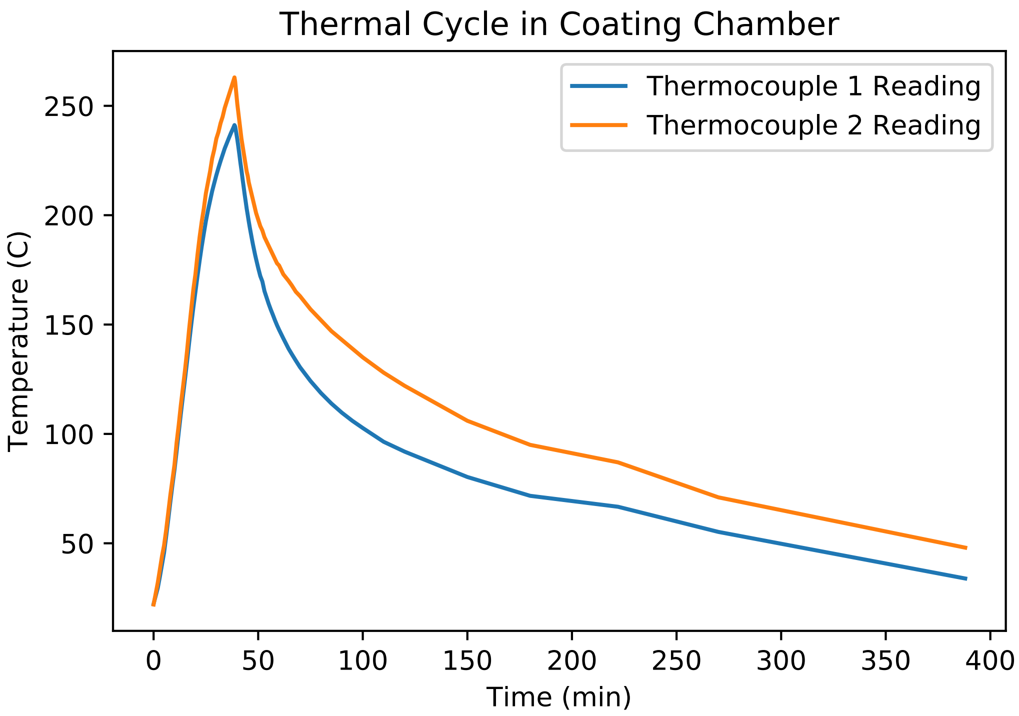
MX Software

ZERODUR Sample Details

Name	Size	Heat Cycle	Total Treatment time
Small	~4 in.	60 C/hr ramp up to 250 C, hold at 250 C for 1 hour, ramp down at 3 C/hr	3.75 hours + 1 hour + 75 hours = 79.75 hours
Medium	~5 in.	60 C/hr ramp up to 250 C, hold at 250 C for 1 hour, ramp down at 6 C/hr	3.75 hours + 1 hour + 37.5 hours = 42.25 hours
Large	~6 in.	60 C/hr ramp up to 250 C, hold at 250 C for 1 hour, ramp down at 10 C/hr	3.75 hours + 1 hour + 22.5 hours = 27.25 hours
Large (Run 2)	~6 in.	Coating Run	~6 hours

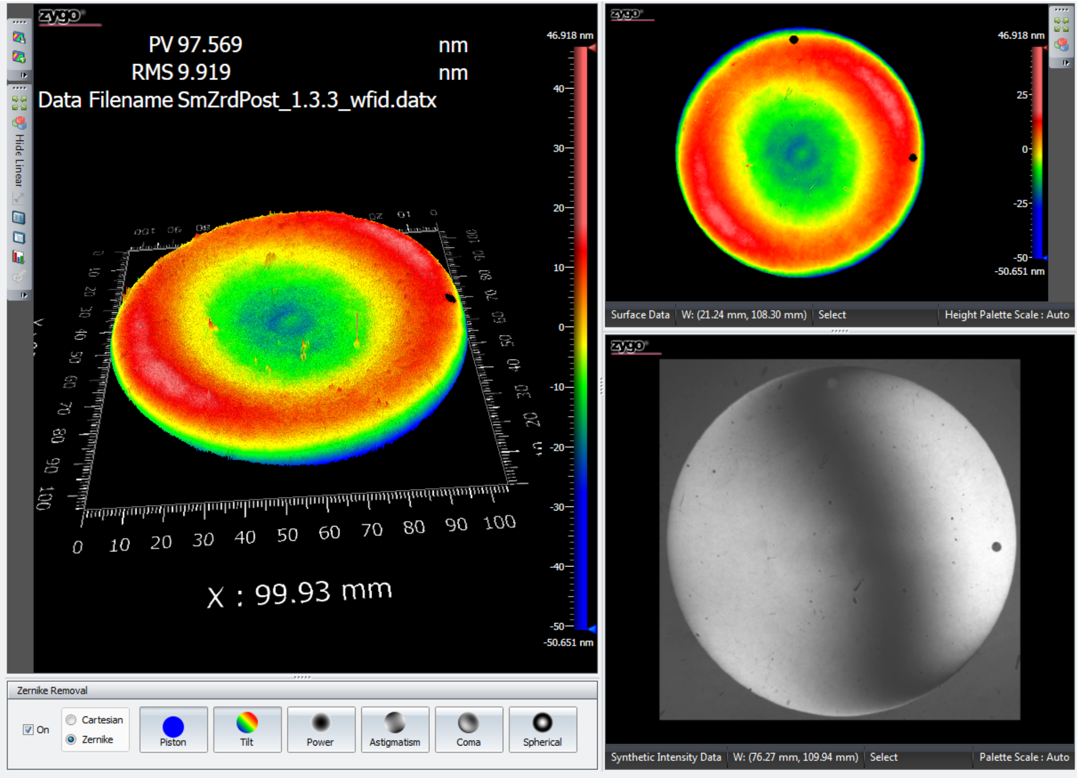
Heating Rates Graphically



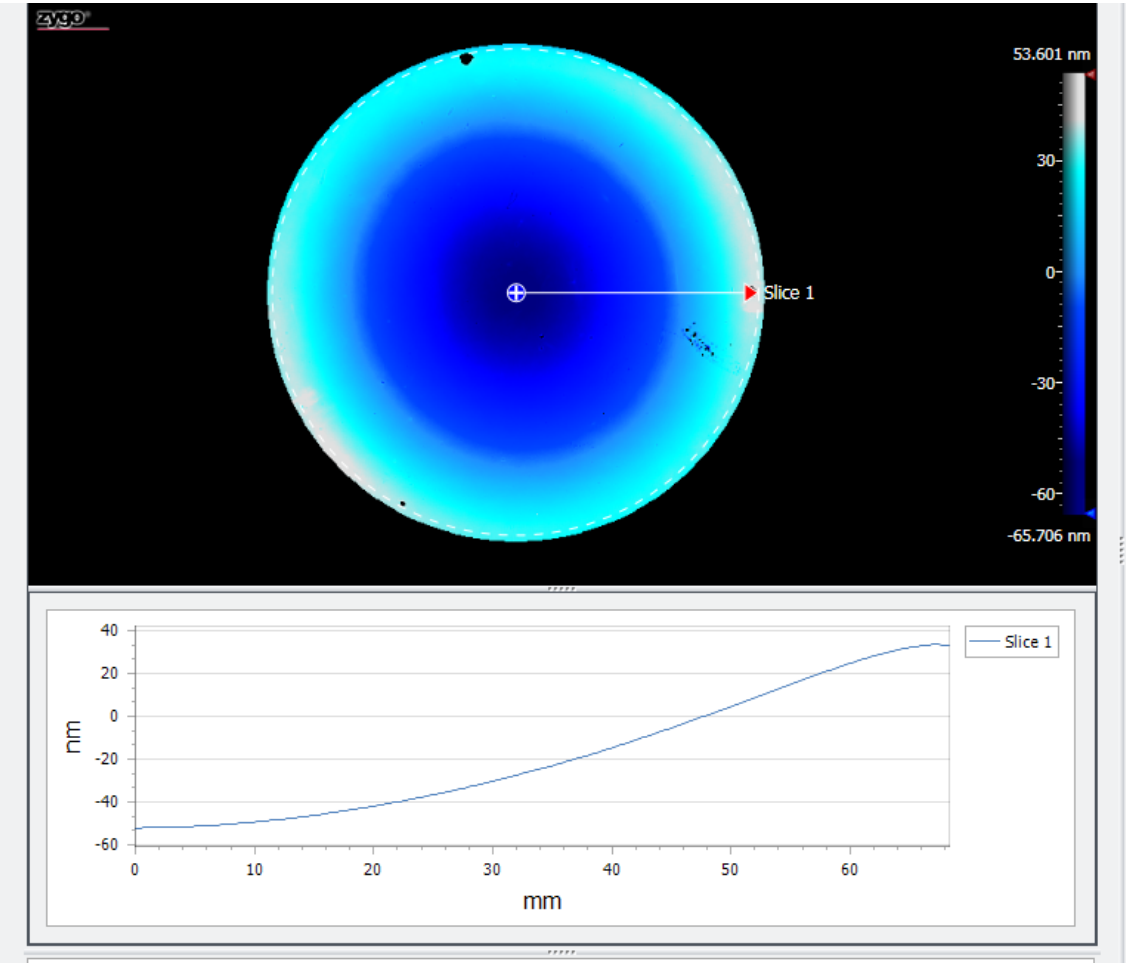


Interferometry: Points of Uncertainty

- In order to improve accuracy, we took into account different points of uncertainty and developed processes to compensate
  - Location relative to transmission flat
  - Orientation of the optic
  - Zoom of the camera
  - Imperfections in the transmission flats
  - “Straying” of the optical mount
  - Vibrations and air current
- To minimize instrument error and measurement
  - Aligned the sample in nearly the same orientation
  - Take the measurement with nulled fringes
  - Use same zoom and lateral scale
  - Tighten fittings of mount
  - Averaging

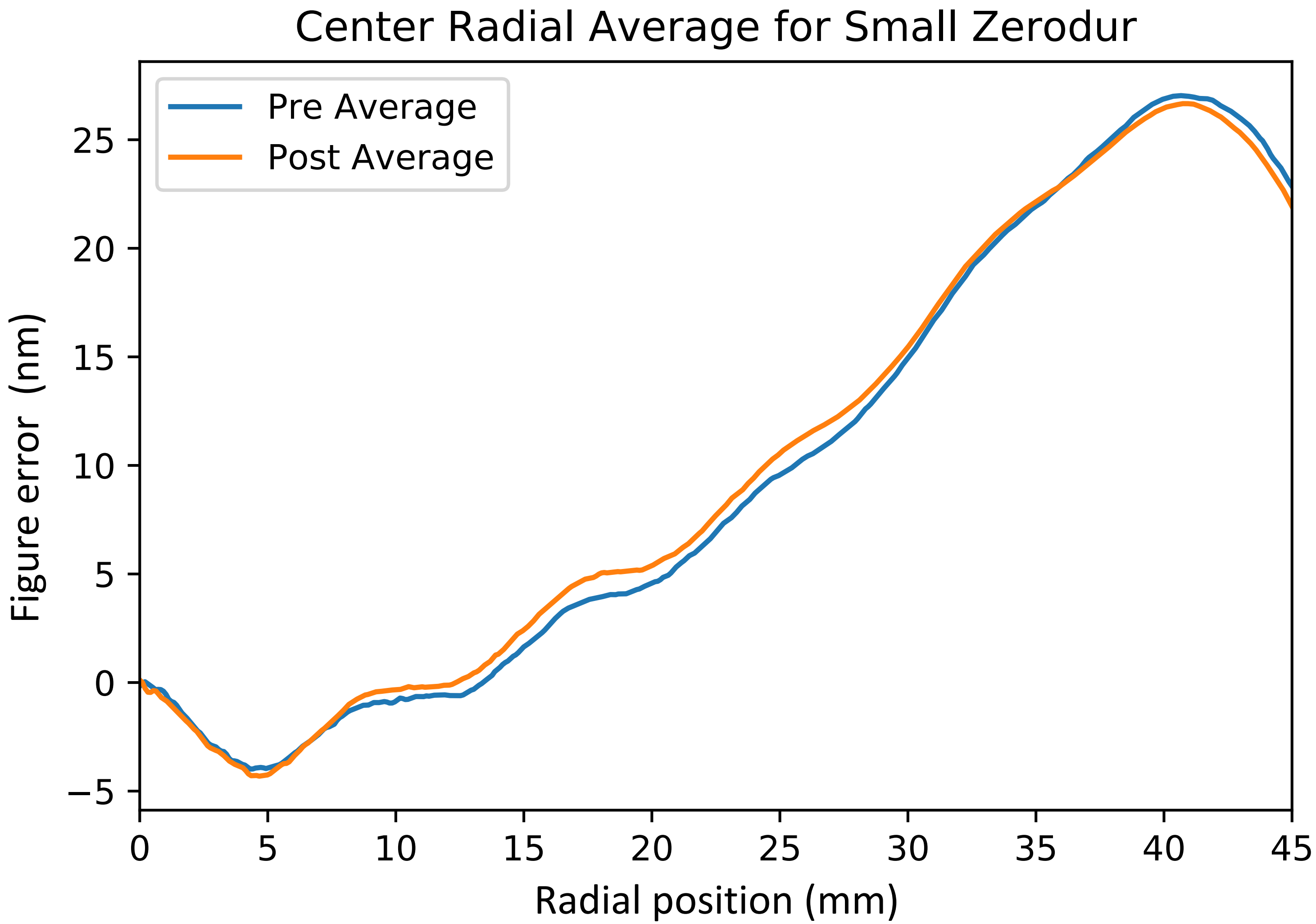


Center Radial Average (CRA)

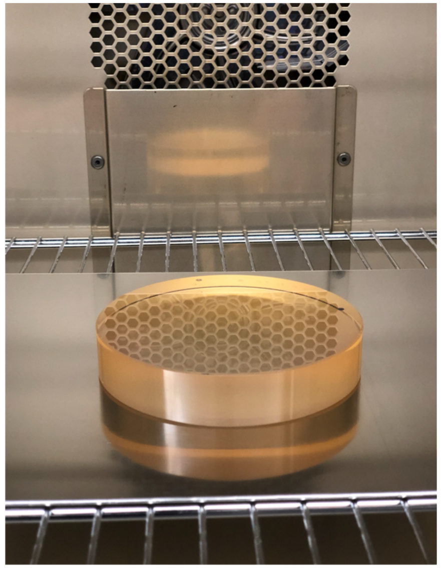


- Performed in the MX software, a Center Radial Average (CRA) performs an averaging sweep from the middle of the measurement to the edge

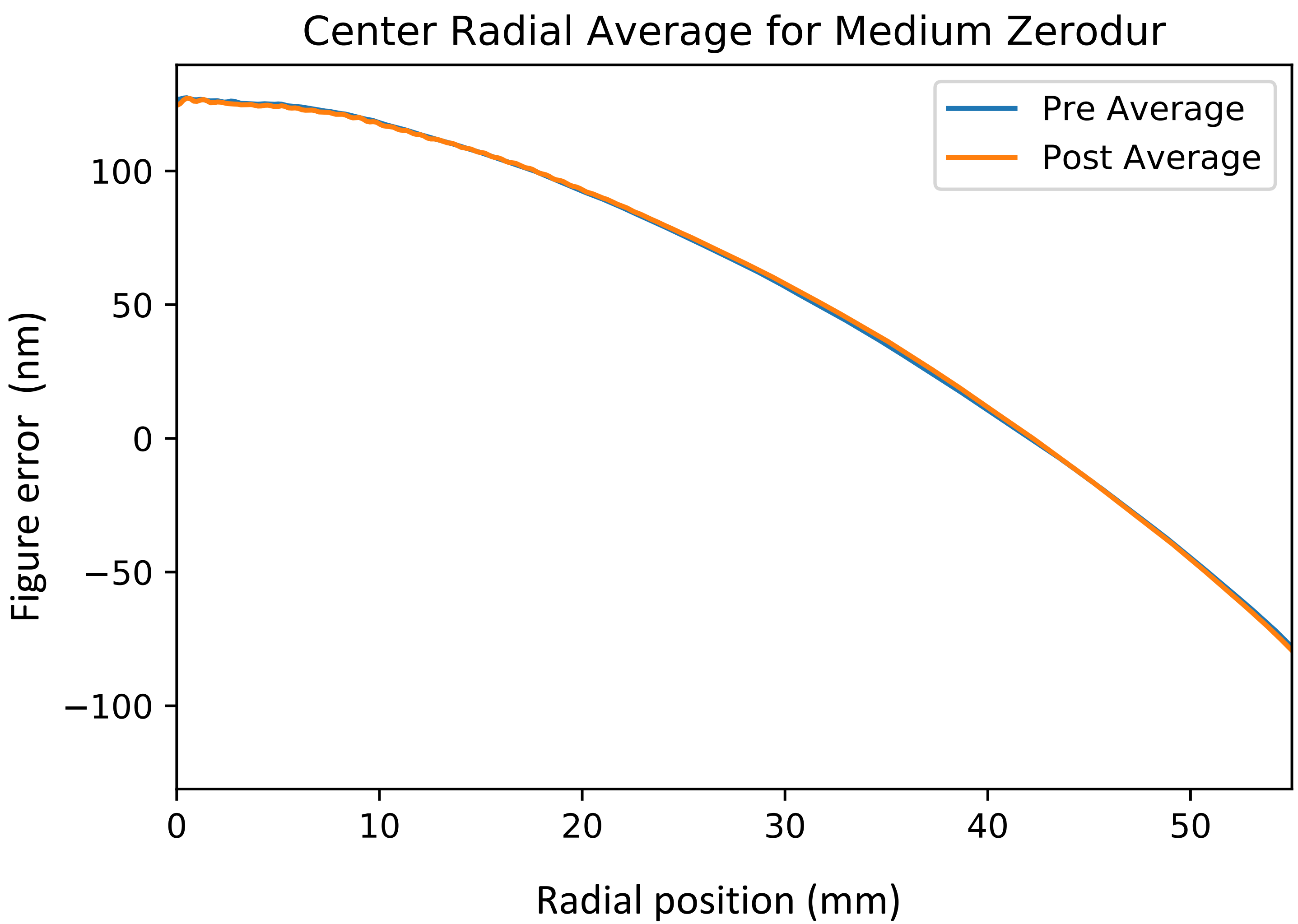
CRA: Small ZERODUR



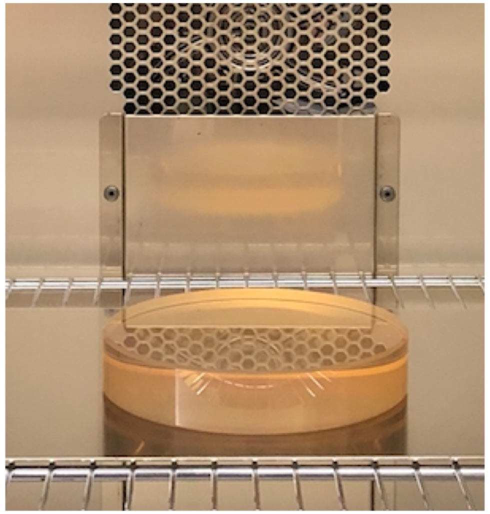
- Treatment is ramp down at 3 C/hr
- Minimal difference observed in the CRA Pre-Treatment vs. CRA Post.
- The difference observed is only about 1 nm, within the measurement error



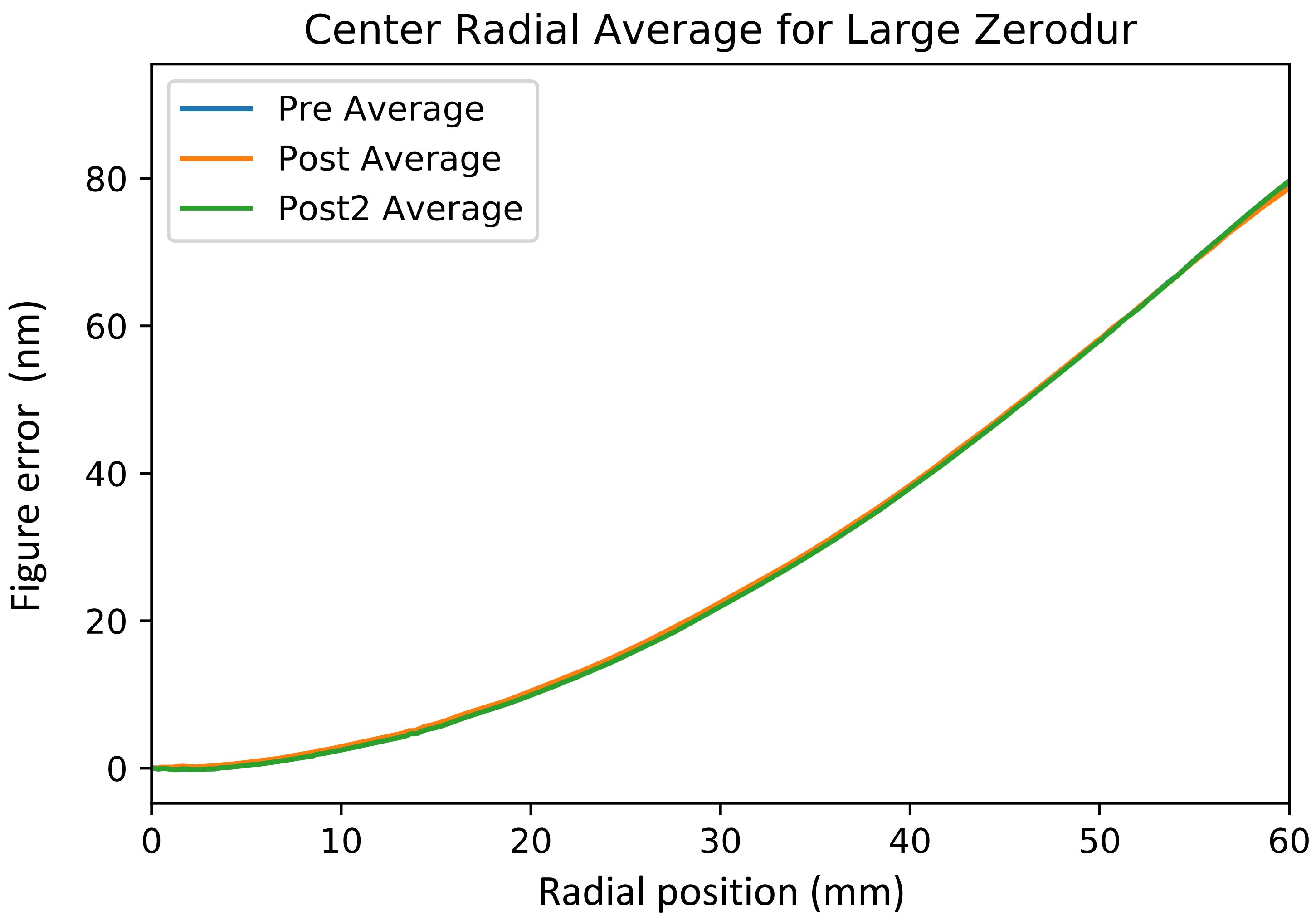
CRA: Medium ZERODUR



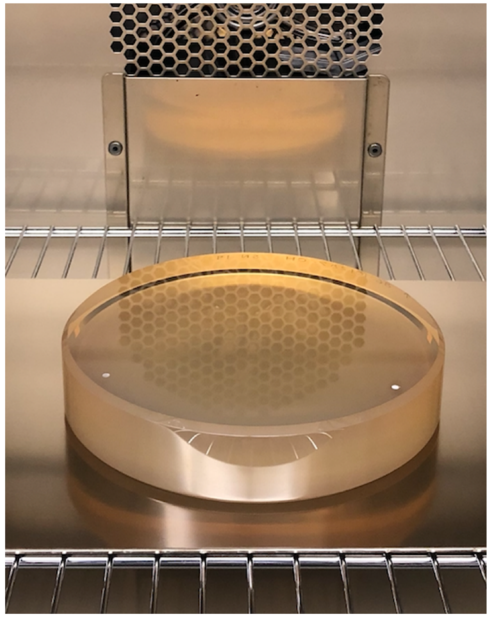
- Treatment is ramp down at 6 C/hr
- Similar to the Small ZERODUR, minimal difference observed in Pre-Treatment and Post-Treatment CRA.



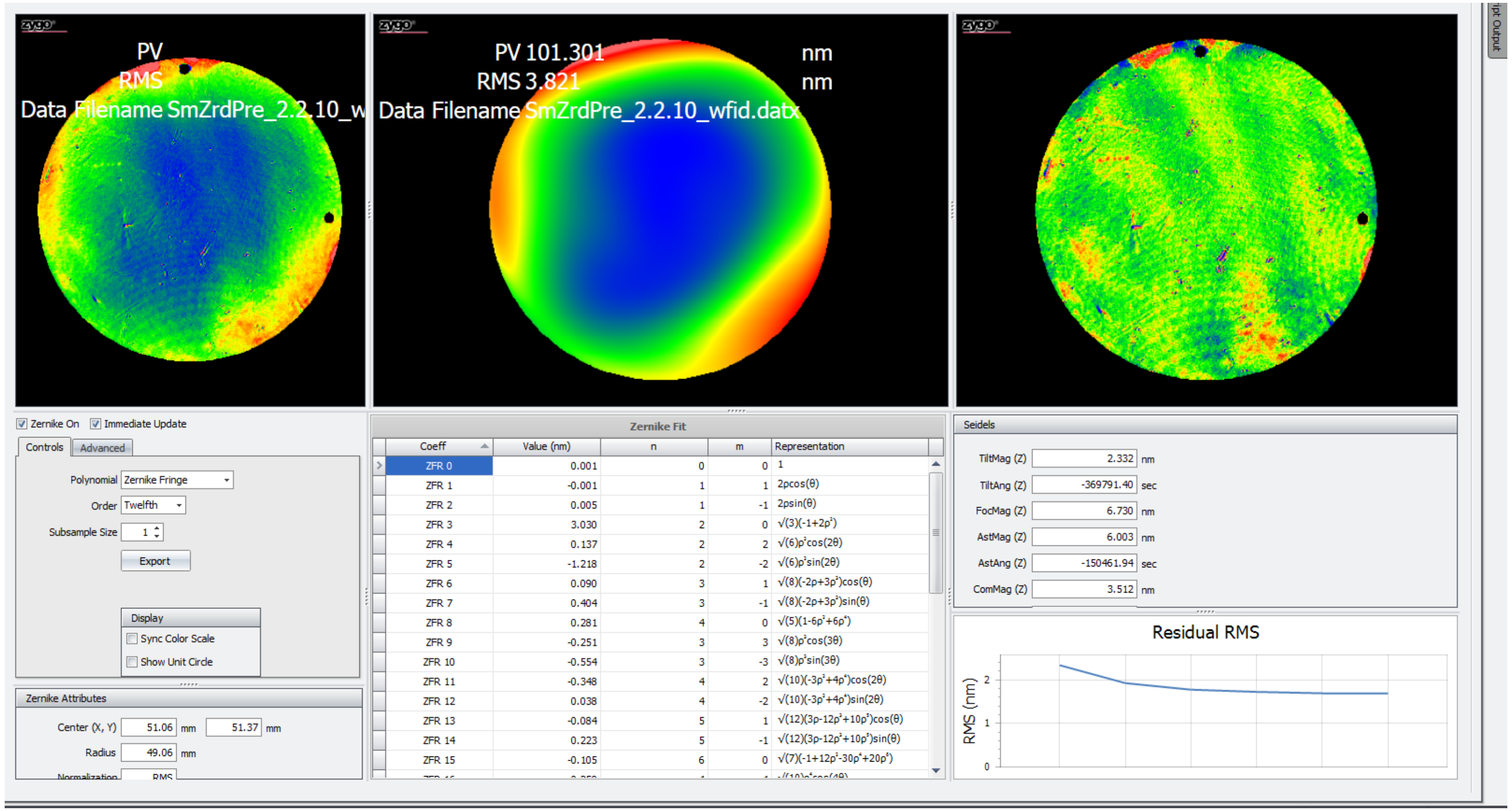
CRA: Large ZERODUR



- Initial treatment is ramp down at 10 C/hr, then the second treatment is according to the coating chamber heating cycle
- Similar to the Small and Medium ZERODUR, minimal difference observed in Pre-Treatment, Post-Treatment, and the coating chamber treatment (Post2) CRA.

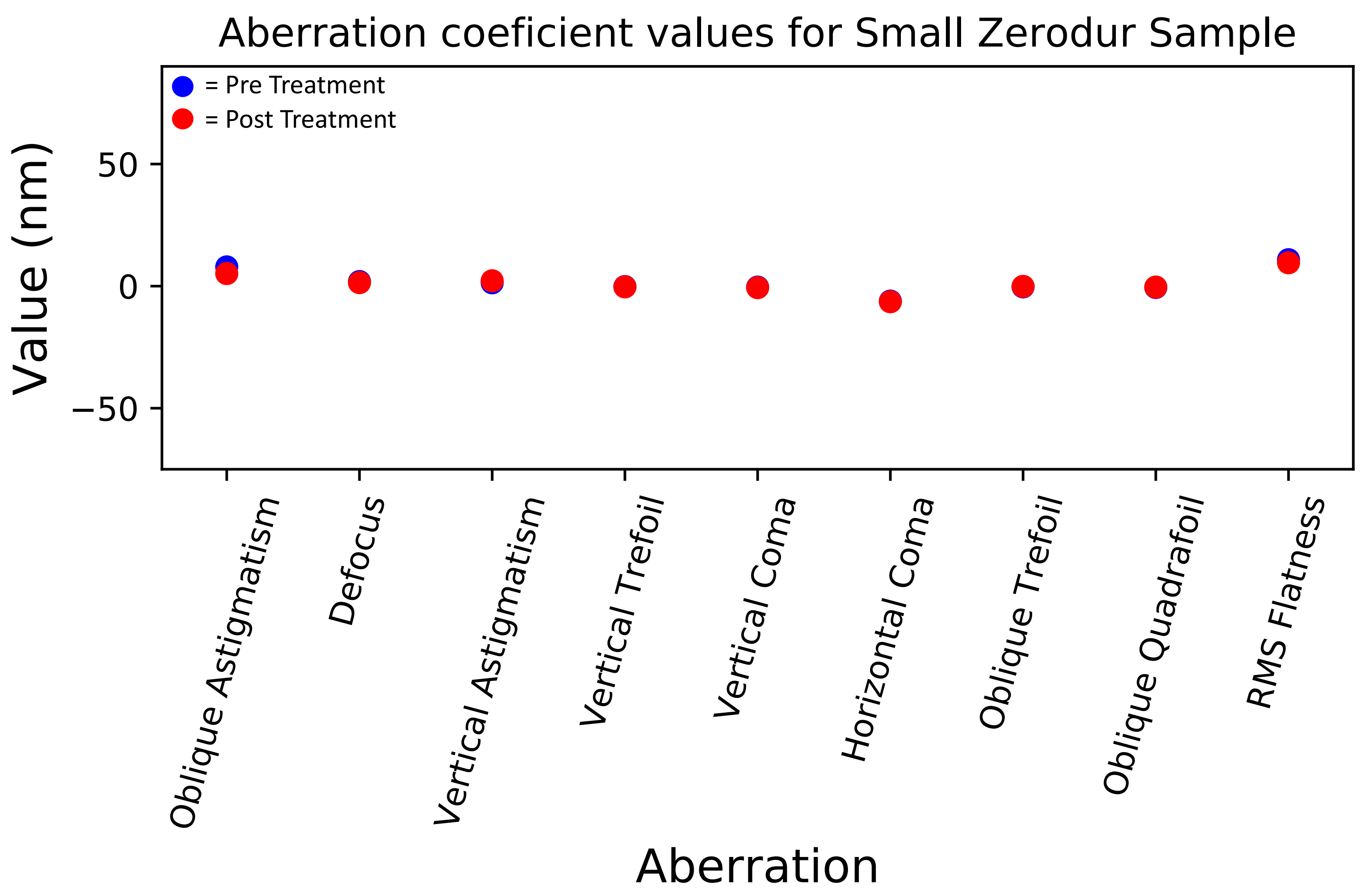


Zernike Fit Aberrations



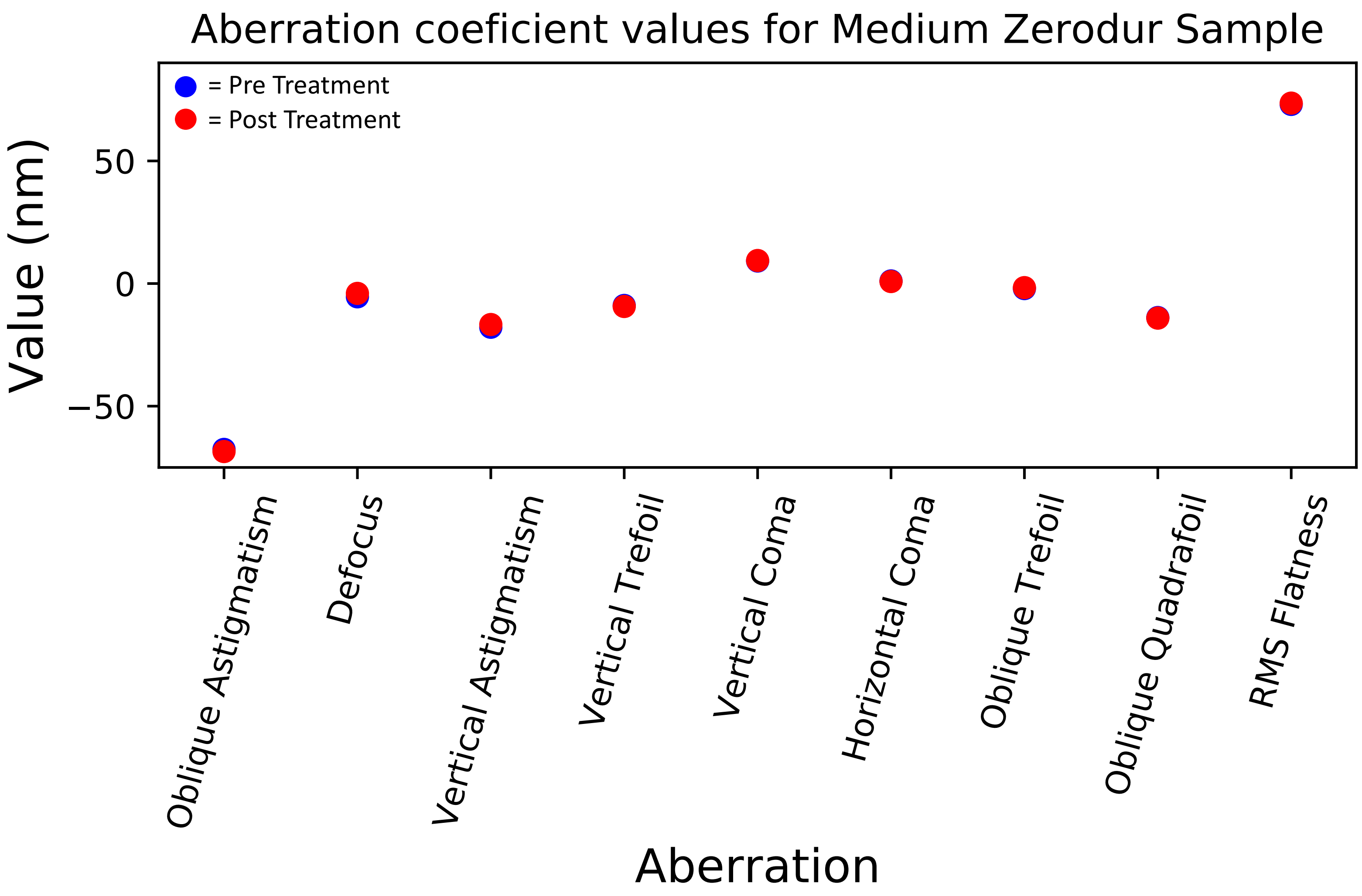
- The MX software can perform twelfth order Zernike Aberration fits. We are analyzing the first ten aberrations.

Small ZERODUR: Zernike Fit Aberrations



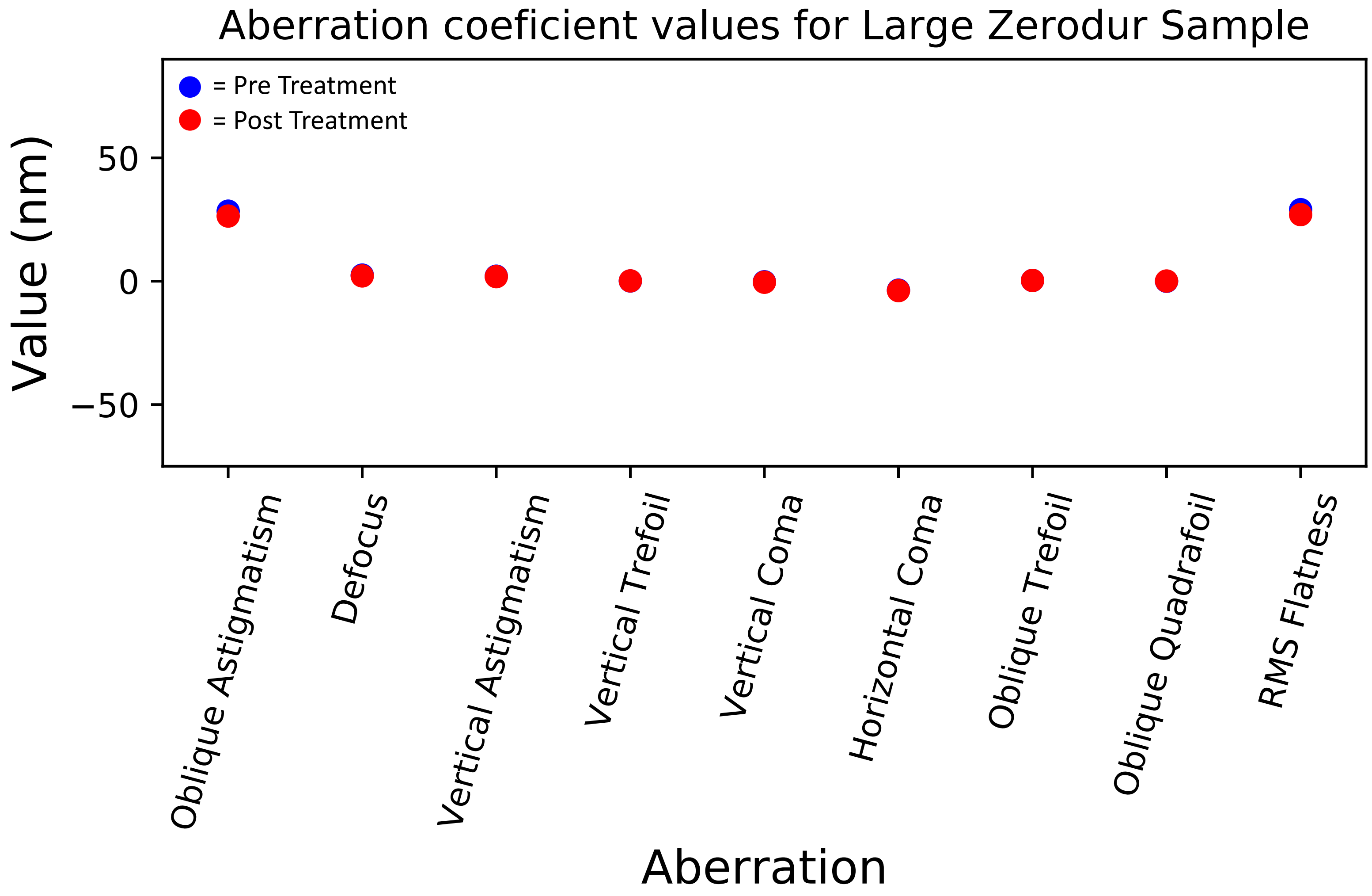
- Largest aberration change is Oblique Astigmatism (2.42 nm)
- Small ZERODUR -> 3 C/hr ramp down

Medium ZERODUR : Zernike Fit Aberrations



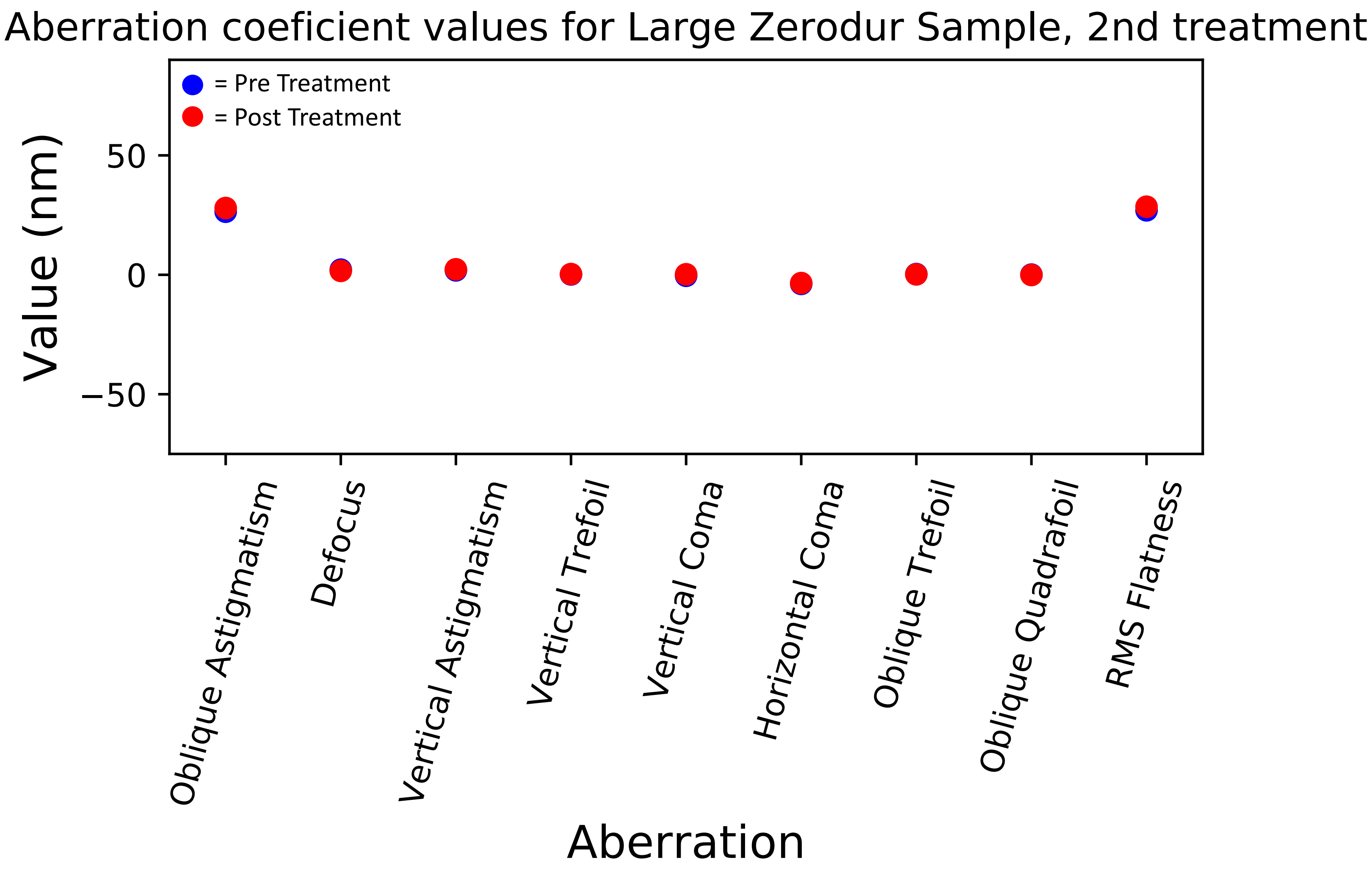
- Largest aberration change is Oblique Astigmatism (1.34 nm), Defocus (.67 nm), and Vertical Astigmatism (.88 nm)
- Medium ZERODUR -> 6 C/hr ramp down

Large ZERODUR : Zernike Fit Aberrations



- Largest aberration change is Oblique Astigmatism (2 nm)
- Large ZERODUR -> 10 C/hr ramp down

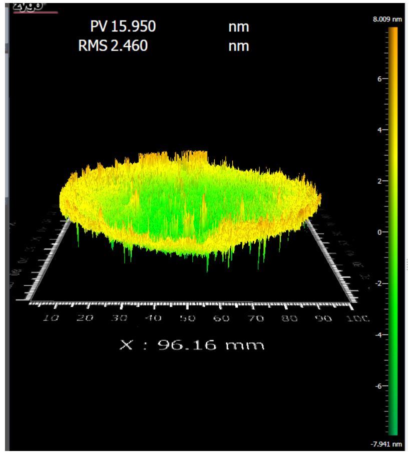
Large ZERODUR 2 : Zernike Fit Aberrations



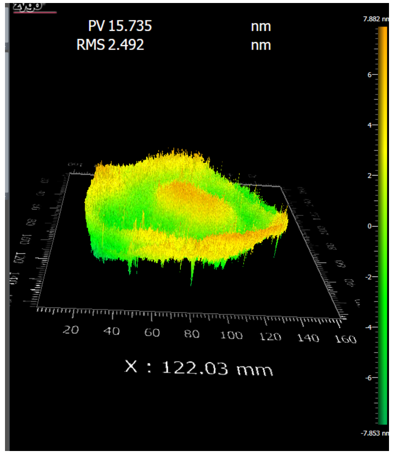
- Largest aberration change is Oblique Astigmatism (1.54 nm)
- Large ZERODUR 2 -> Coating chamber heat treatment

Visual Subtraction Maps

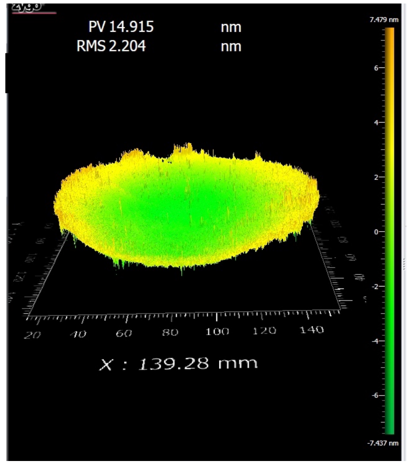
Small ZERODUR



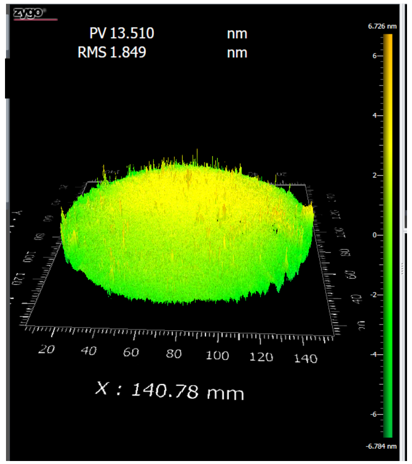
Medium ZERODUR



Large ZERODUR



Large ZERODUR: chamber cycle



- Subtraction maps for all three ZERODUR substrates pre- and post-heat treatment
- The residual difference was estimated to be around 1.8-2.5 nm RMS for all samples
- These values are small enough that they are considered within uncertainty errors

Conclusions

- ZERODUR substrates did not show significant changes in center radial average figure error or flatness for heating and cooling at various thermal rates
- Analysis of interferometric data showed the largest measurable changes in Zernike aberrations was Oblique Astigmatism
- The RMS flatness value for the subtractions maps (before and after heat-treatment) was less than or equal to 2 nm
- Any change observed is small enough to be considered within the measurement error

Funding Source Acknowledgment

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- GSFC FY19 Internal Research & Development (IRAD) Program

Backup Slides

High-Temperature Deposition Al+MgF_2

3-step coating process:

- ✓ Al coat the substrate at room temperature to the planned layer thickness
- ✓ As soon as possible after the Al deposition, overcoat the Al layer and substrate at room temperature with a thin 4-5 nm layer of MgF_2 in order to protect the Al from oxidation and contamination.
- ✓ Heat the substrate to maximum temperature and overcoat the thin MgF2 , Al, and substrate with the planned thickness of MgF2.