Modeling the Schott ELZM Thermal Soak Test

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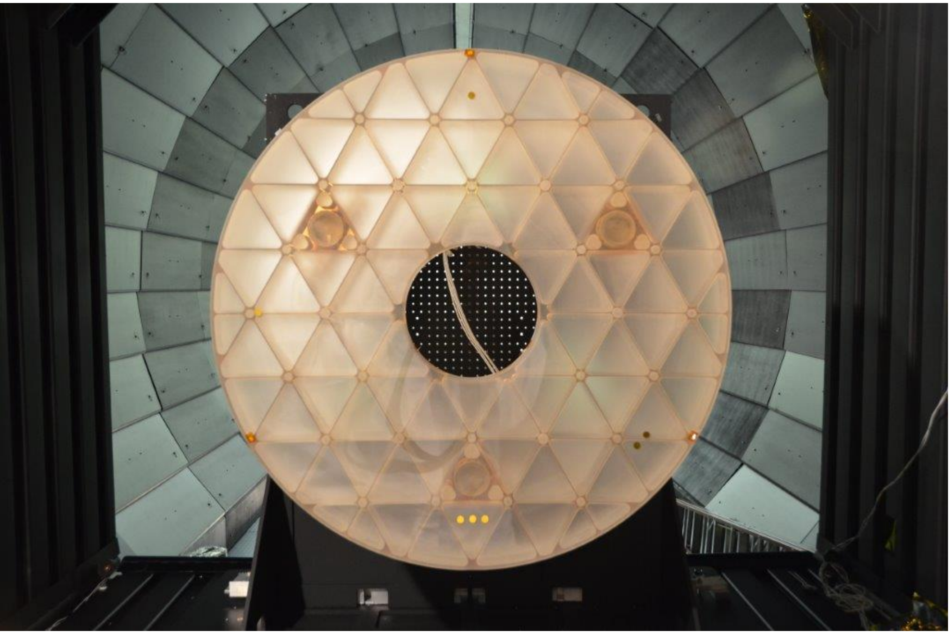
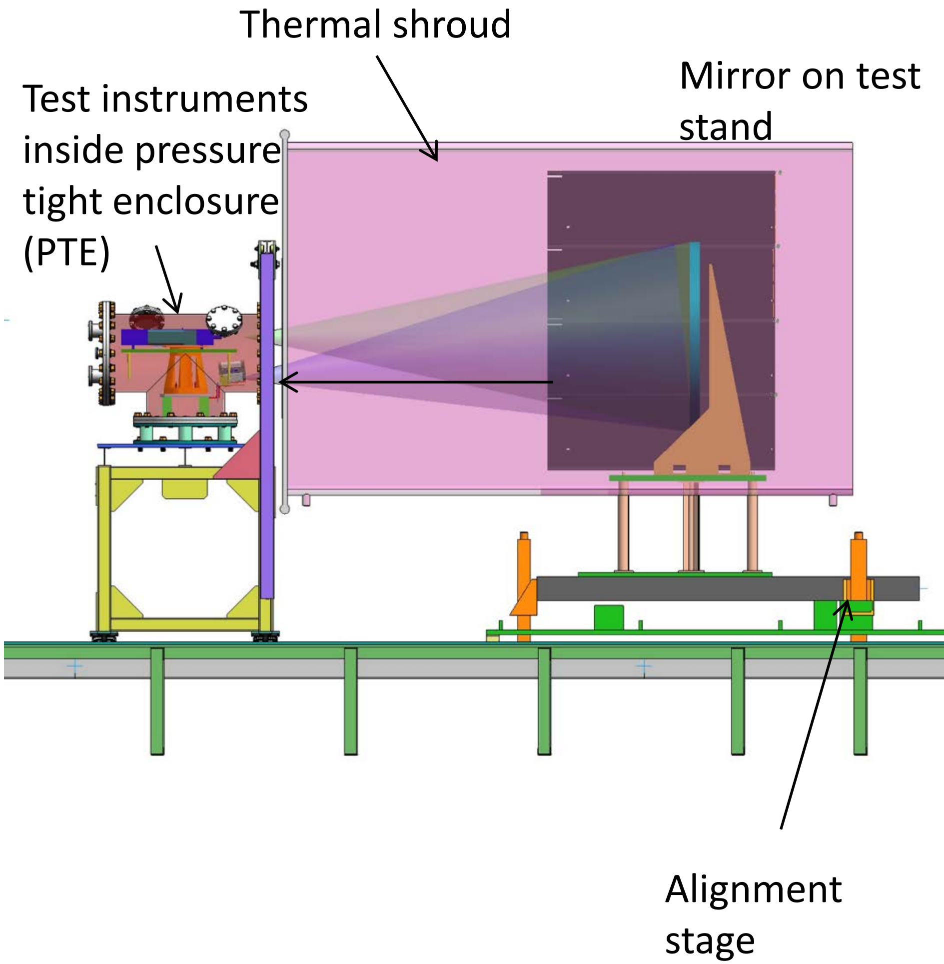
Opto-thermal test of Zerodur Mirror





Test Measured Data at 250K

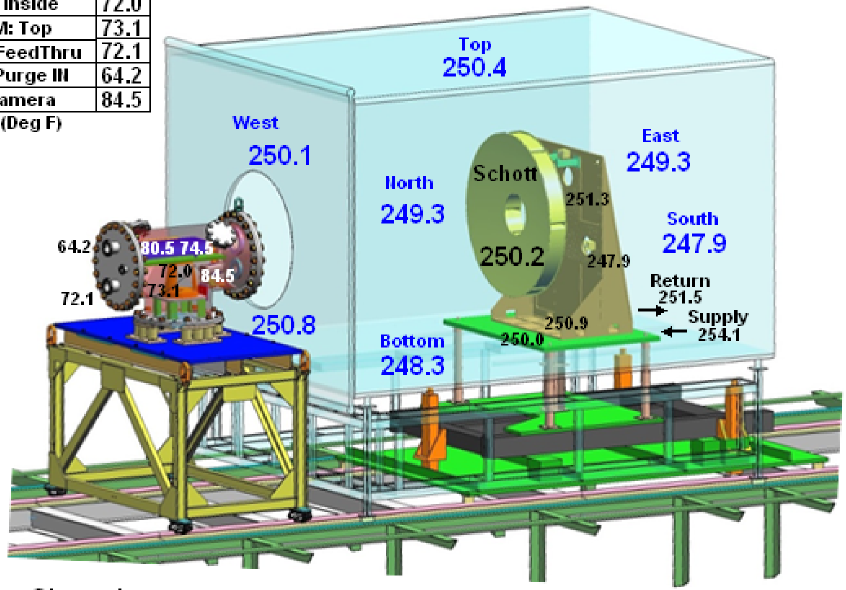
09/16/16 08:10:57

AMTD2 / Schott Cryo Test

PTE

PhaseCam East	74.5
PhaseCam West	80.5
PTE: Inside	72.0
ADM: Top	73.1
Cable FeedThru	72.1
PTE: Purge IN	64.2
IR Camera	84.5

(Deg F)

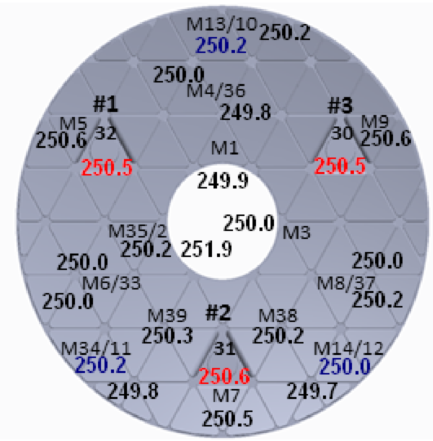


Shroud

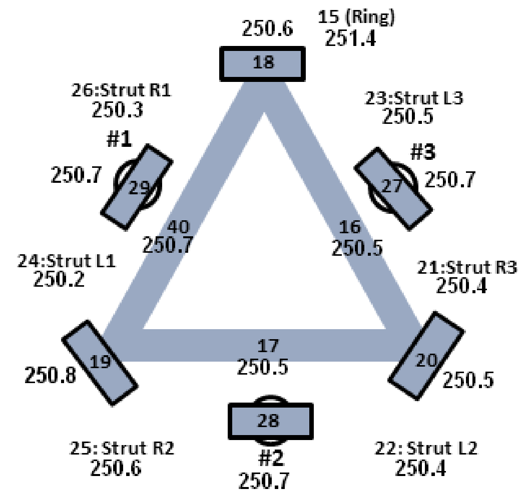
Top	250.4
North	249.3
South	247.9
Bottom	248.3
West Top	250.1
West Bottom	250.8
East	249.3

(Kelvin)

	Shroud			Schott	
Average	249.4	K	Average	250.2	K
Rate	-0.1	K/HR	Rate	-0.1	K/HR
Max	250.8	K	Max	251.9	K
Min	247.9	K	Min	249.7	K
Grad	3.0	K	Grad	2.2	K



North (Front View) South

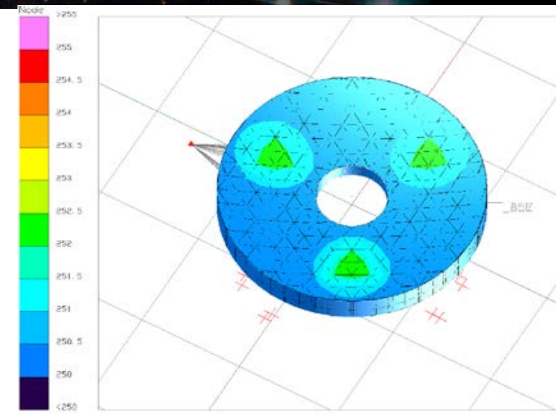


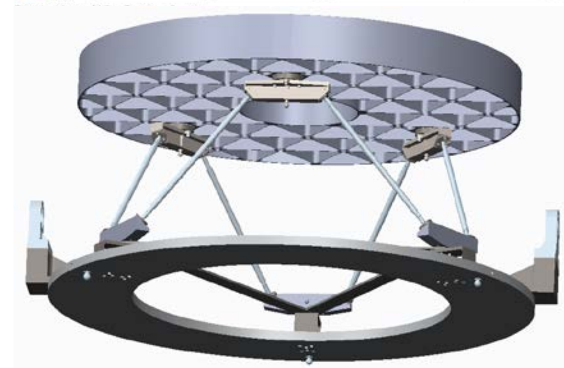
M1- Top Hole	249.9
M2 - North Hole	251.9
M3 - South Hole	250.0
M4 - 12:00	250.0
M5 - 10:00	250.6
M6 - 8:00	250.0
M7 - 6:00	250.5
M8 - 4:00	250.2
M9 - 2:00	250.3
M10- Top Edge	250.2
M11 - 8:00 Edge	249.8
M12 - 4:00 Edge	249.7
M13 - Top Front	250.2
M14 - 4:00 Front	250.0
M33 - 8:00 (w/M6)	250.0
M34 - 8:00 (w/M11)	250.2
M35 - 8:00 (w/M2)	250.2
M36 - 12:00 (w/M4)	249.8
M37 - 4:00 (w/M8)	250.0
M38 - 5:00	250.2
M39 - 7:00	250.3
30 - South Pad	250.5
31 - Bottom Pad	250.6
32 - North Pad	250.5
15 - 12:00 Ring	251.4
16 - Delta_3	250.5
17 - Delta_2	250.5
18 - Top Bracket	250.6
19 - South Bracket	250.8
20 - North Bracket	250.5
21 - Strut R3	250.4
22 - Strut L2	250.4
23 - Strut L3	250.5
24 - Strut L1	250.2
25 - Strut R2	250.6
26 - Strut R1	250.3
27 - South Mount	250.7
28 - Bottom Mount	250.7
29 - North Mount	250.7
40 - Delta_1	250.7

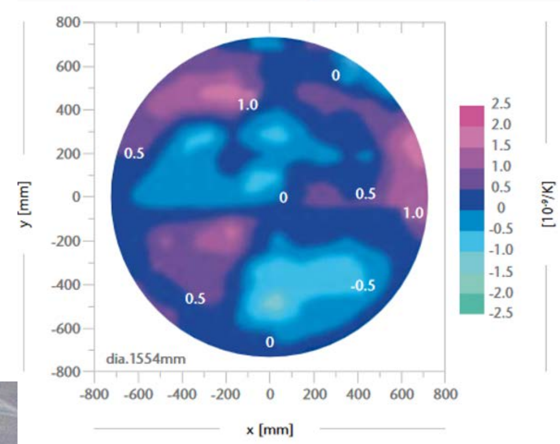
(Kelvin)

Error Sources

- Error due to Thermal Gradients
  - Thermal gradients cause mirror to bend
  - Caused by non-zero CTE and gradients
- Error due to Mount Effects
  - Mirror mount not athermalized, but very compliant flexures
  - Hexapod legs grow and bend mirror
- Error due to CTE inhomogeneity
  - CTE gradients + isothermal temperature change have effect similar to thermal gradients
- Instrumentation Error

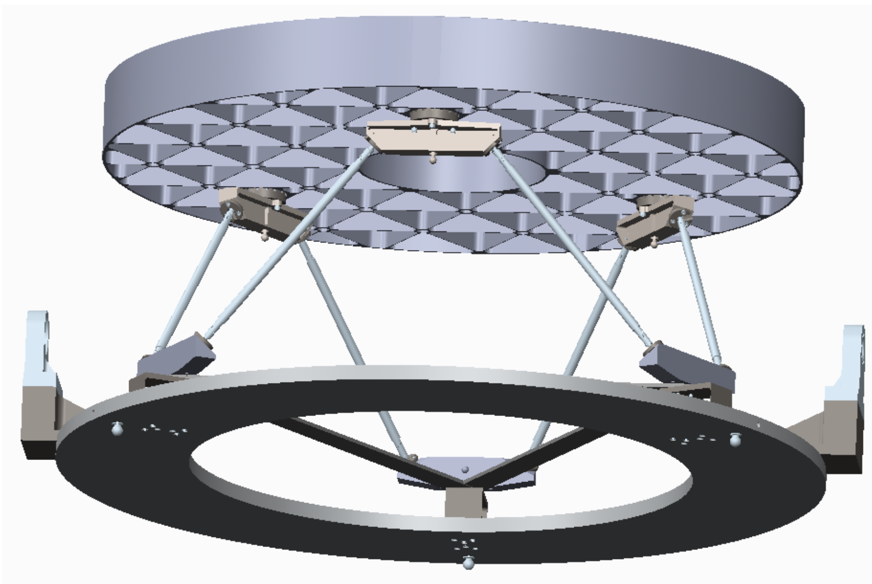




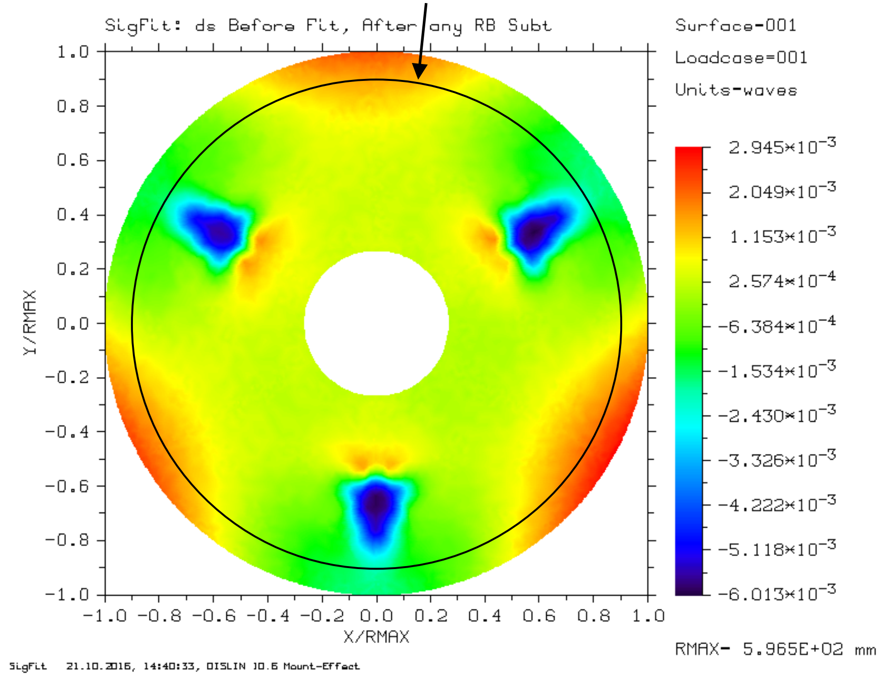


Error due to Mount

- RMS SFE=0.81nm
- Likely sources of error:
  - Incorrect material properties

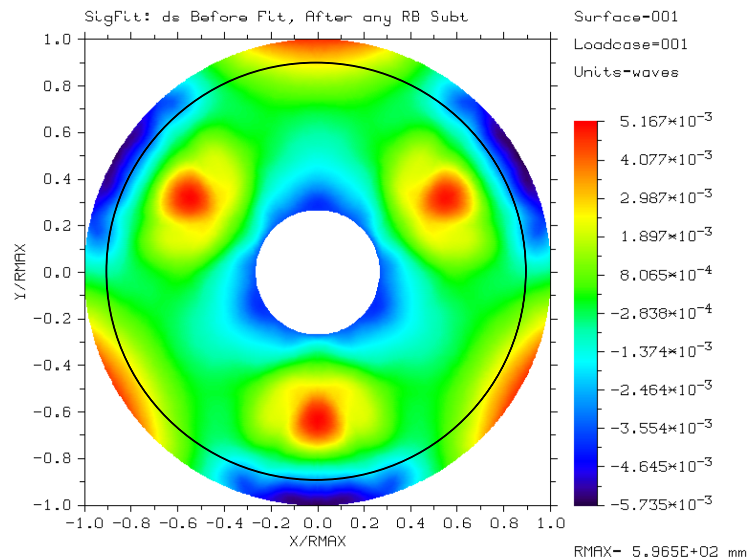


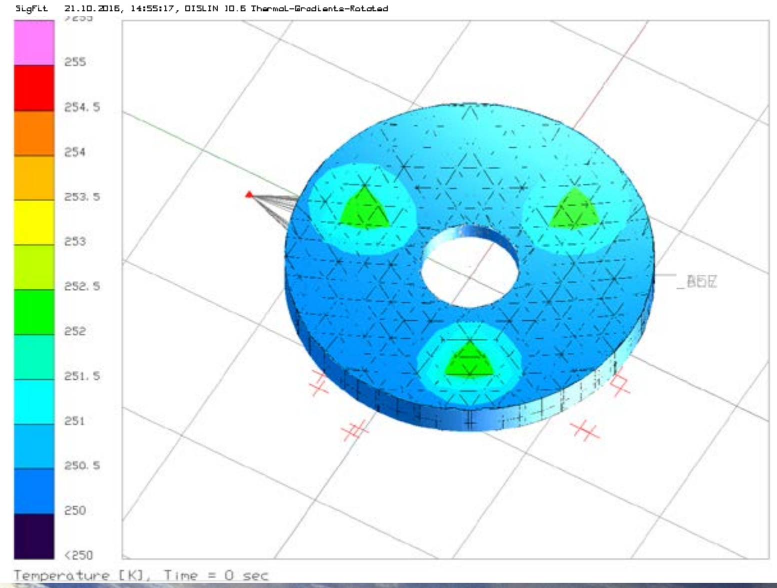
The test was sub-aperture and only the area enclosed in the circle was measured



Error due to Thermal Gradients

- RMS SFE=1.28nm
- Likely sources of error:
  - Different temperature distribution
  - CTE(250K) of this Zerodur mirror





Error due to CTE Inhomogeneity

Table 2.3
CTE homogeneity tolerances

CTE (0°C; 50°C) Homogeneity tolerances	
up to 18 tons	$< 0.03 \cdot 10^{-6}/K$
up to 6 tons	$< 0.02 \cdot 10^{-6}/K$
up to 0.3 tons	$< 0.01 \cdot 10^{-6}/K$

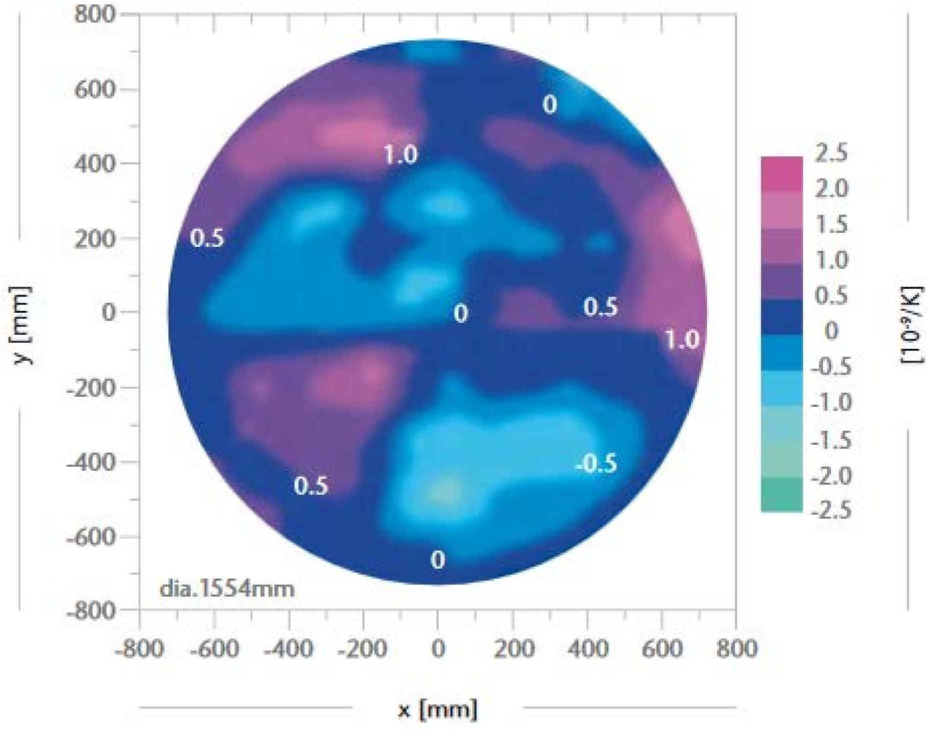
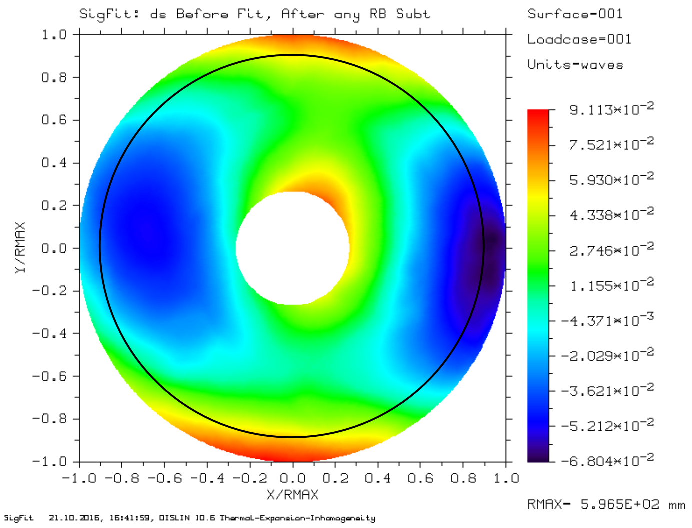
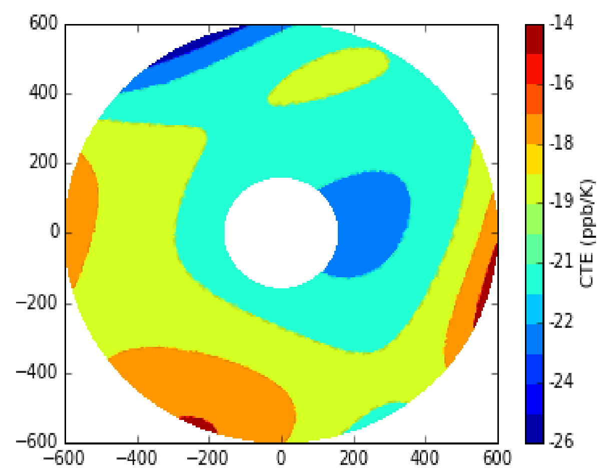


Figure 2.2
CTE distribution within a 1.5 m diameter blank with a measured CTE homogeneity of $0.004 \cdot 10^{-6}/K$

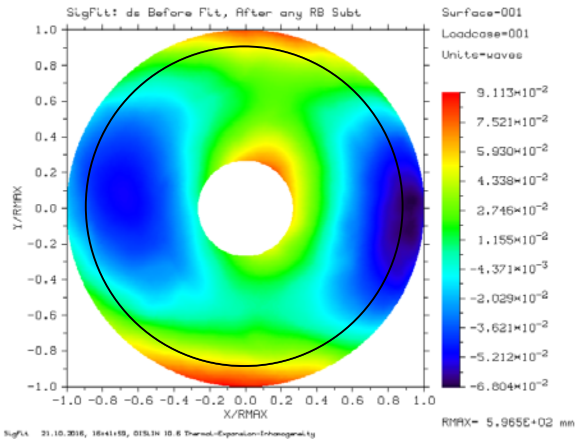
Error due to CTE Inhomogeneity

- RMS SFE=8.75nm
- Likely sources of error:
  - Incorrect “randomly generated” CTE inhomogeneity shape
  - Incorrect CTE inhomogeneity P-V (assumed 10ppb/K)

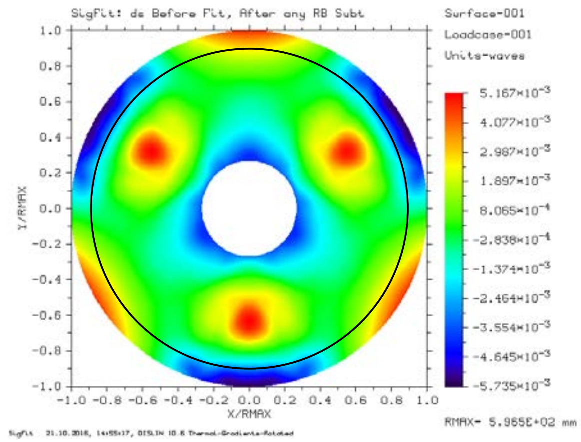




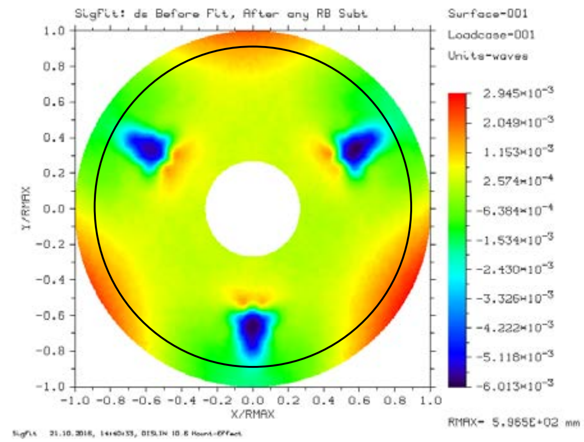
Surface Figure Error Budget



CTE Inhomogeneity + Bulk Temperature Change



Mirror Temperature Gradient + CTE



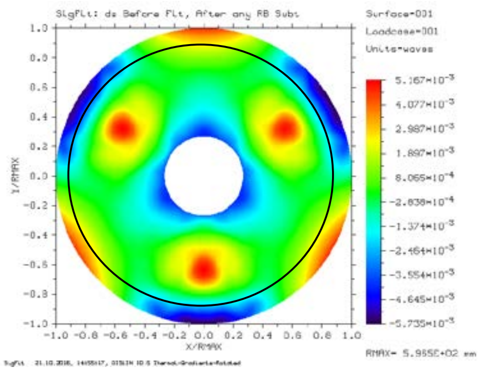
Mount Stiffness and CTE + Bulk Temperature Change

Total SFE (nm)	Inhomogeneity SFE (nm)	Gradient SFE (nm)	Mount SFE (nm)
21.45	21.4	1.28	0.81

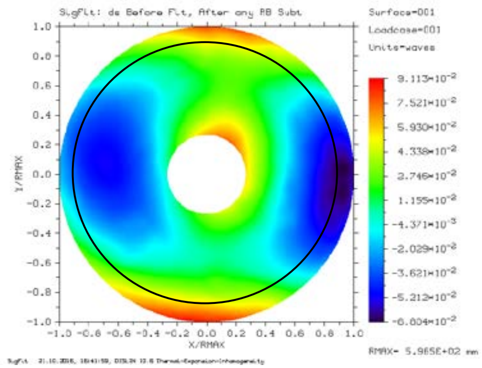
Disclaimer: some material properties were unknown and assumed; large uncertainty in epoxy properties.

294 to 250

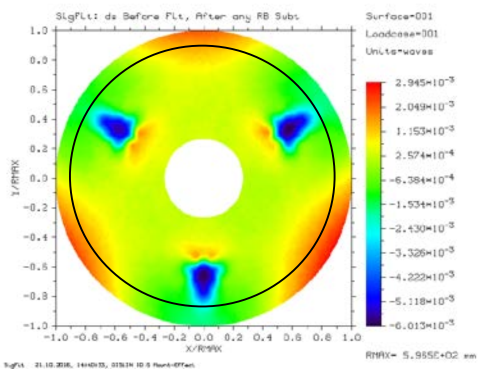
A Prior Analysis Results



Thermal Gradients*
(1.28 nm RMS)



Inhomogeneity**
(21.4 nm RMS)

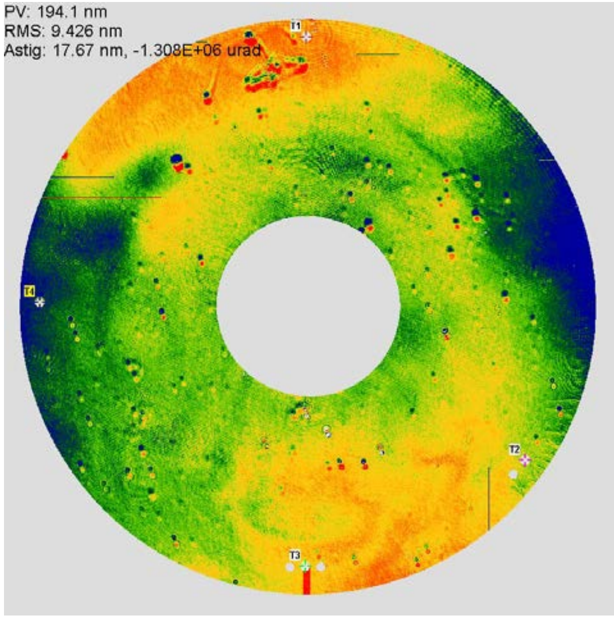


Mount Effects
(0.81 nm RMS)

*Exact temperature distribution could not be known in advance. CTE(T) was not known in advance (0.02ppm/K assumed at all temperatures)

**CTE Inhomogeneity was not known a priori. A random CTE map was generated that had a 10ppb/K peak to valley.

Test Results



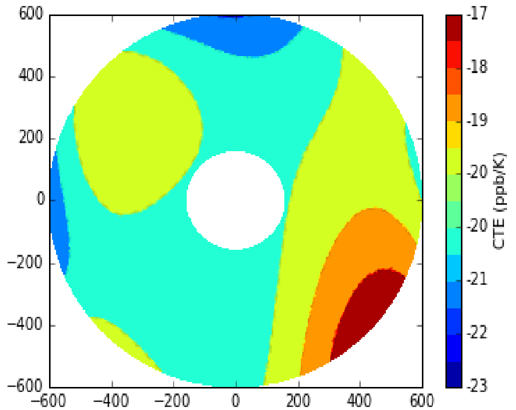
Measured SFE (9.4 nm RMS)

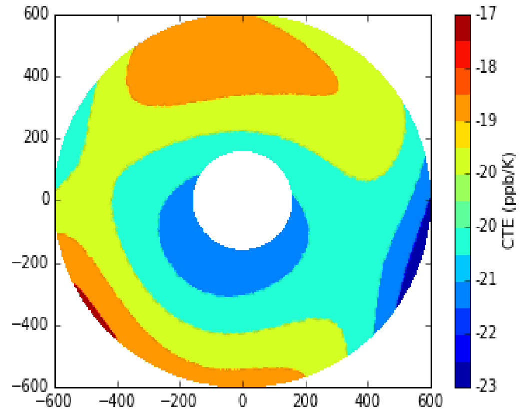
Conclusion

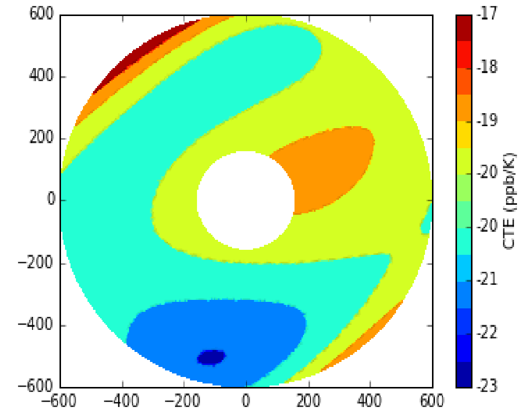
Analysis can match measured SFE by adjusting the assumed CTE inhomogeneity to a new CTE inhomogeneity that is roughly 5ppb/K peak to valley. This is within the range of measured Zerodur CTE inhomogeneity peak to valleys.

Generated Multiple Homogeneities

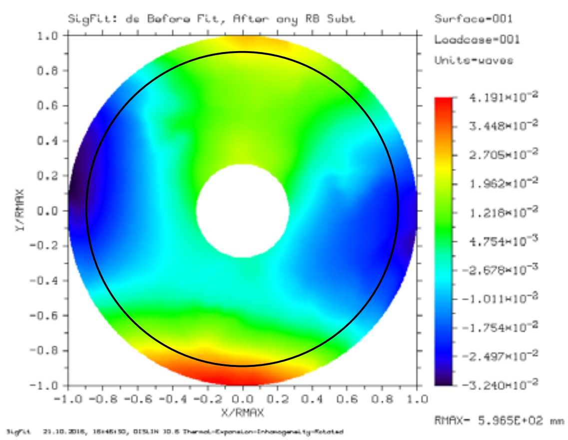
CTE Homogeneity Maps



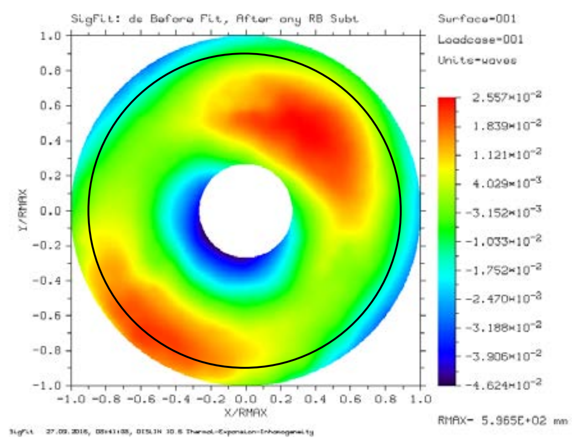




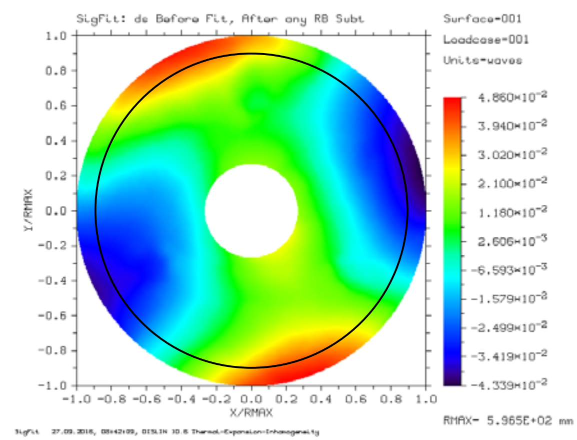
Surface Figure Error



9.5 nm RMS SFE

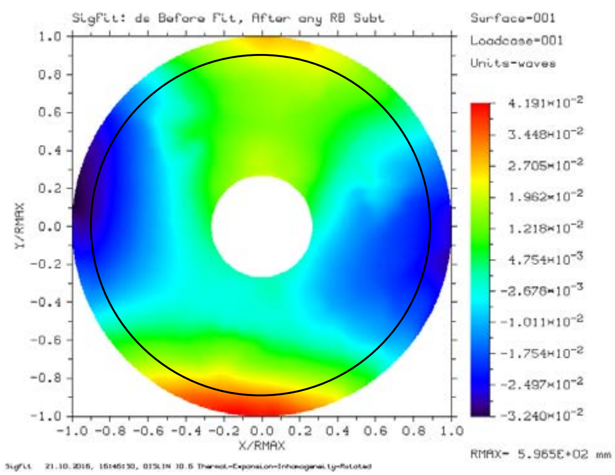


8.7 nm RMS SFE



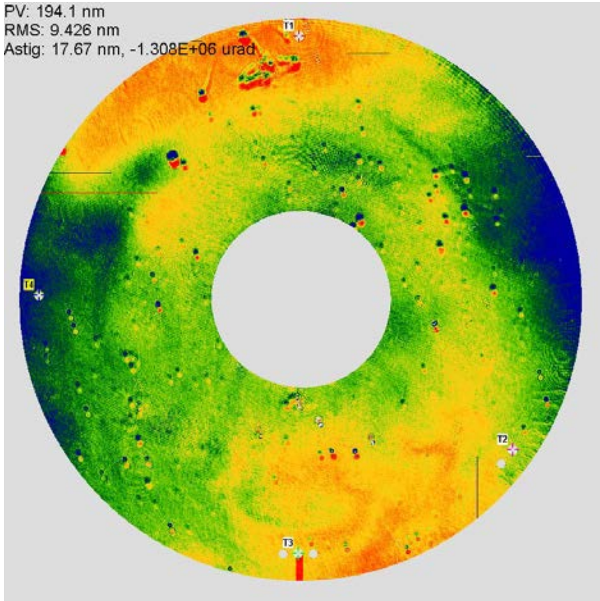
13.1 nm RMS SFE

294 to 250



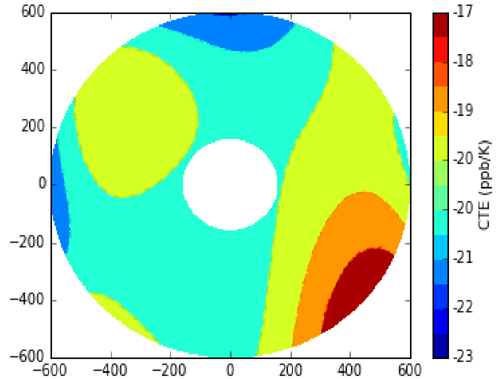
New Homogeneity* (9.55 nm RMS)

*CTE Inhomogeneities randomly generated until one matched. P-V homogeneity changed to 5 ppb/K.



Measured SFE (9.4 nm RMS)

Homogeneity Map. CTEs in ppb/K



Conclusion

- A 5 ppb/K peak-to-valley inhomogeneity produced 9.55nm RMS of SFE and an root-sum-squared SFE estimate of 9.6nm RMS.
- Zerodur boules have been measured to have a 5 ppb/K peak-to-valley CTE inhomogeneity, therefore, 5ppb/K peak-to-valley inhomogeneity is reasonable.
- Further investigation will match test results to an even greater extend.