Modeling the Schott ELZM Thermal Soak Test

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Opto-thermal test of Zerodur Mirror

Test instruments inside pressure tight enclosure (PTE)

Thermal shroud

Mirror on test stand

Alignment stage
Surface Figure Error (SFE) 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 bend the mirror

• Instrumentation Error
SFE due to Mount

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

The test was sub-aperture and only the area enclosed in the circle was measured.
SFE due to Thermal Gradients

- RMS SFE = 1.28nm
- Likely sources of error in analysis:
  - Different temperature distribution (~2K \(\Delta T\))
  - CTE(250K) of this Zerodur mirror (20ppb/K)
Test Measured Data at 250K

AMTD2 / Schott Cryo Test

*Likely anomalous measurement ignored
SFE due to CTE Inhomogeneity

Table 2.3
CTE homogeneity tolerances

<table>
<thead>
<tr>
<th>CTE (0°C; 50°C) Homogeneity tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 18 tons</td>
</tr>
<tr>
<td>up to 6 tons</td>
</tr>
<tr>
<td>up to 0.3 tons</td>
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</tbody>
</table>

From the Schott Zerodur July 2011 Katalog [sic]
SFE due to CTE Inhomogeneity

- RMS SFE = 21.4 nm
- Likely sources of error in analysis:
  - Incorrect “randomly generated” CTE inhomogeneity shape
  - Incorrect CTE inhomogeneity P-V (assumed 10ppb/K)
SFE Budget

<table>
<thead>
<tr>
<th>Total SFE (nm)</th>
<th>Inhomogeneity SFE (nm)</th>
<th>Gradient SFE (nm)</th>
<th>Mount SFE (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.45</td>
<td>21.4</td>
<td>1.28</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Disclaimer: some material properties were unknown and assumed; large uncertainty in epoxy properties.
A Prior Analysis Results

- Thermal Gradients* (1.28 nm RMS)
- Mount Effects (0.81 nm RMS)
- Inhomogeneity** (21.4 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.
First two were measured with the old dilatometer metrology. All others measured with the new dilatometer metrology.

Ralf Jedamzik, et al.  
"Effects of thermal inhomogeneity on 4m class mirror substrates", *Proc. SPIE 9912, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation II*, 99120Z (July 22, 2016); doi:10.1117/12.2234287; [http://dx.doi.org/10.1117/12.2234287](http://dx.doi.org/10.1117/12.2234287)
Generated Multiple Homogeneities

All maps are 5ppb/K P-V CTE Inhomogeneity

CTE Homogeneity Maps

Surface Figure Error

9.5 nm RMS SFE  8.7 nm RMS SFE  13.1 nm RMS SFE
New 294K to 250K

New Homogeneity* (9.55 nm RMS)

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

Conclusion

• A 5 ppb/K peak-to-valley inhomogeneity produced 9.55nm RMS of SFE and a 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.
Acknowledgements

Marshall Space Flight Center (MSFC)
• Ron Eng and the XRCF team for setting up and performing the test
• Phil Stahl for helping design the test and interpret results

University of New Mexico (UNM)
• Tony Hull for helping design the test and interpret results

Schott
• Provided the mirror

Arizona Optical Systems (AOS)
• Designed the support structure
Questions or Comments?