Advantages of Silicon Carbide Telescopes for Small-Satellite Imaging Applications

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1. Introduction

Optical Telescope Assemblies (OTAs) implemented in silicon carbide (SiC) provide performance advantages for space applications but have been predominately implemented in the government sector. A new generation of lightweight and thermally-stable designs is commercially available, expanding the application of SiC to small satellites.

One of the major challenges in satellite telescope design is the ability to maintain performance in the thermal environment of low-earth orbits (LEO). Thermal stability analyses of two similar OTAs designed by AOS, one of SiC and one of Aluminum with Glass mirrors, are compared in this poster. The effect of temperature changes under soak conditions on ground resolved distance (GRD) are explored using image analysis.

2. Advantages of SiC

SiC possesses the highest combination of specific stiffness (E/ρ) and thermal stability (k/α_t) of any optical grade material. These properties make SiC ideal for maintaining optical and mechanical performance throughout launch and in the dynamic thermal environment of low-earth orbit (LEO).

Material Property	SiC	Aluminum	Fused Silica
Elastic Modulus, E (GPa)	330	68.9	72.7
Mass Density, ρ (kg/m^3)	3000	2700	2201
Specific Stiffness, E/ρ (10^9 m^2/s^2)	0.11	0.026	0.033
Thermal Expansion, α_t (10^{-6}/K)	2.4	23.6	0.52
Thermal Conductivity, k (W/m-K)	220	170	1.3
Thermal Stability, k/α_t (W/µm)	92	7	2.5

Table 1: Room-temperature properties of POCO Graphite SuperSiC-Si, 6061-T6 Aluminum, and Corning HPFS Fused Silica.

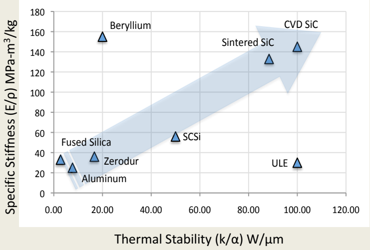

Figure 1: Specific Stiffness vs. Thermal Stability for commonly used mirror materials

3. SiC vs. Traditional Al-Glass Telescopes

Small satellite OTAs are typically required to meet optical performance specifications across a temperature range of approximately -30° C to +40°C for LEO applications. The analysis performed explores the impact to focus and GRD as a function of temperature. The telescope design used in the analysis is a two mirror, reflective system with a clear aperture of 125-mm designed to enable GRD ≤ 7.5-m for NIR wavelengths at an altitude of 500-km.

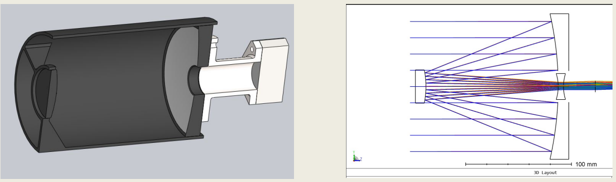

Figure 2 and 3: Cross- sectional view of AOS 125-mm telescope design and ray trace diagram used for optical analysis.

SiC Telescope Delivers Consistent Optical Performance In Thermal Soak Conditions

Point spread function (PSF) plots are shown at -30, -20, +20 and +40°C for SiC and Aluminum-Glass telescopes. A narrow PSF corresponds to less image blur at the detector. The dominant impact to the telescope resulting from change in temperature is displacement in the optics which causes defocus (and thus image blur at the detector). Figure 12 illustrates the comparative focal shift in the SiC and Aluminum-Glass systems. Image blur is illustrated by the PSF resulting from the various shifts in focal length (Figure 4 – 11). The impact on GRD is then calculated. (Figure 13). The difference in thermal soak sensitivity is also an indicator of the relative sensitivity to thermal gradients, which are much more challenging to correct for in low-earth orbits.

PSF for SiC Telescope:

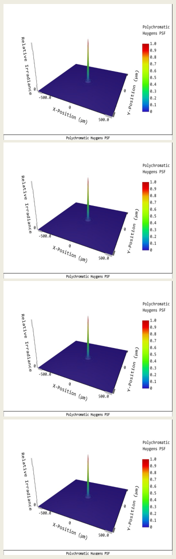

Figure 4-7: PSF plots of SiC telescope as thermal soak conditions range from -30 to +40°C.

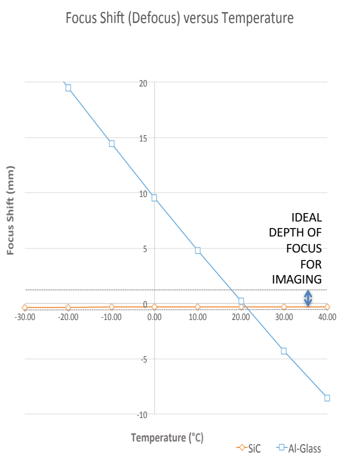

Figure 12: Defocus versus Temperature in SiC and Aluminum-Glass telescopes from -30 to +40°C.

PSF for Aluminum - Glass Telescope:

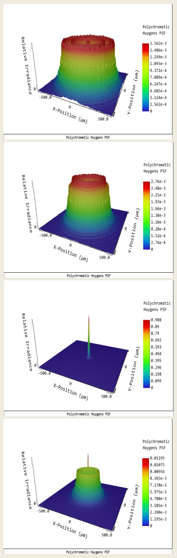

Figure 8-11: PSF plots of Aluminum-Glass telescope as thermal soak conditions range from -30 to +40°C.

4. Impact of Thermal Soak on GRD

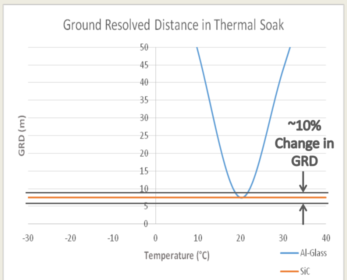

Figure 13: Ground resolved distance (GRD) versus temperature for SiC and Aluminum-Glass telescopes from -30 to + 40°C.

5. Conclusion

- SiC system maintains the designed GRD over the typical required temperature range (± 35°C).
- Aluminum-Glass system performance rapidly decays, even after ± 2°C, from its optimal GRD.

Thermal properties of SiC allow for telescope systems that outperform Aluminum-Glass telescopes. In soak conditions, SiC focus shift is nominally zero. Furthermore, SiC shows up to 37x better performance across the temperature range for ground resolved distances over Aluminum-Glass telescopes in thermal soak conditions. Real-world scenarios present more complex challenges that reveal even more extensive benefits of optimized material selections.

6. References

1. K. J. Kasunic, D Aikens, D. Swabowski, C. Ragan, F. Tinker, “Technical and Cost Advantages of Silicon Carbide Telescopes for Small-Satellite Imaging Applications”, SPIE Optical Engineering and Applications, San Diego 2017, paper #10402-11.
2. Tinker, F., Xin, K., “Aspheric Finishing of Glass and SiC Optics”, Optical Fabrication and Testing, Monterey, California United States, June 24-28, 2012, Figuring and Finishing Science (OM4D),
3. “SAGE Handbook of Remote Sensing”, T. A. Warner, M.D. Nellis, G.M. Foody, (SAGE Publications Ltd., London, 2009), 101-102.
4. F.P. Incropera, D.P. DeWitt, T.L. Bergman, A.S. Lavine, “Introduction to Heat Transfer”, (Wiley Publishing, New Jersey, 2006) Fifth Edition.
5. SuperSiC Material Properties [Online], POCO Graphite, http://poco.com/MaterialsandServices/tabid/124/Default.aspx [22 June 2017].