Thermo-optical Simulation and Experiment for the Assessment of Single, Hollow, and Large Aperture Retroreflector for LLR

ARAKI, Hiroshi[1], KASHIMA, Shingo[1], NODA, Hirotomo[1], KUNIMORI, Hiroo[2], CHIBA, Kouta[3], MASHIKO, Hitomi[3], KATO, Hiromasa[3], OTSUBO, Toshimichi[4], MATSUMOTO, Yoshiaki[5], TSURUTA, Seiitsu[1] ASARI, Kazuyoshi[1], HANADA, Hideo[1], YASUDA, Susumu[6], UTSUNOMIYA, Shin[1], TAKINO, Hideo[7]

1: NAOJ, 2: NICT, 3: Iwate University, 4: Hitotsubashi University, 5: PTI Co., Ltd., 6: JAXA, 7: Chiba Institute of Technology

Lunar laser ranging (LLR) has made a significant contribution especially to Selenodesy and General Relativity. The accuracy of LLR is less than 2 cm due to the improvement of the ground station. However, the lunar retroreflector has room for improvement on the ranging accuracy [1].

The single element retroreflector (SERR) has an advantage on the accuracy over the arrayed corner cube on the Moon because it has no internal optical path difference. SERR whose aperture is 20 cm can yield two times reflection performance compared with the A15 retroreflector [2]. Thus we investigated the thermal deformation and optical degradation of the hollow type SERR (hereafter CCM; Corner Cube Mirror) with 20 cm aperture through the thermo-optical simulation, because the prism type SERR with the same aperture made of synthetic quarts shows severe optical degradation due to the inhomogeneity of the refractive index as well as the weight problem.

Mathematical model of CCM (Figure 1) is prepared on the lunar surface with its optical axis aligned to the Earth at −43.3 degrees in the lunar latitude (the same latitude as Tycho crater) to simulate the equilibrium temperature and thermal deformation of the CCM. Single crystal silicon (Si) and the CLEARCERAM™-Z EX (OHARA Inc.; hereafter CCZ-EX®) are selected as CCM material for higher thermal diffusivity, lower thermal expansion, and higher specific stiffness. Other parts are made of carbon fiber reinforced plastics (CFRP). Thermal Desktop®, ANSYS®12, and CodeV10.6SR1 are used for the temperature, deformation, and optical evaluation, respectively.

The deformation of CCM is 40–50 μm (Si) or 1 μm (CCZ-EX®) at the lunar noon if the CCM is fixed perfectly to the structure on multi-points, while the deformation is less than 0.25 μm at most if the perfectly fixed point of the CCM is limited to one. The optical performance of the former CCM is quite poor (Strehl ratio < 0.1; Figure 2), while it is excellent for the latter case (Strehl ratio > 0.9; Figure 2). Through this simulation, it has turned out for the first time that 20-cm aperture CCM made of single-crystal Si or "ultra-low expansion glass–ceramics" such as CCZ-EX® can be used for CCM with no thermal control if the perfectly fixed point of CCM is limited to one.

In addition, high temperature annealing from 100 to 1000 °C is confirmed effective experimentally to enhance the adhesive strength between optically contacted Si surfaces, which is an important knowledge for the fabrication process of CCM.

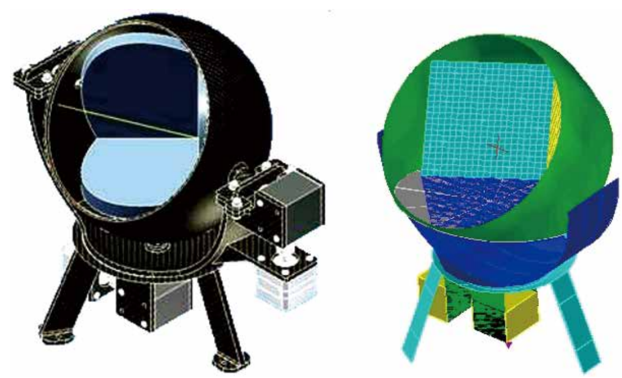

Figure 1: [left] General view of the CCM system. [right] Mathematical model of the CCM system for Thermal Desktop®. CCM aperture is 20 cm.

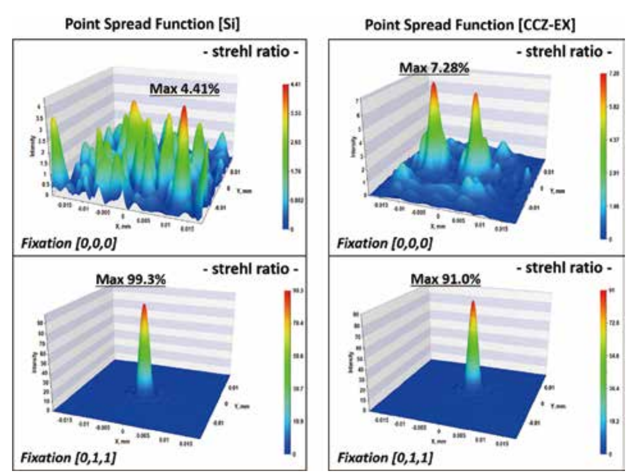

Figure 2: Strehl ratios of the aberrated focus image by CCM. [Upper left] CCM made of Si fixed on 3 points perfectly. [Lower left] CCM made of Si fixed on 3 points and one of them is perfectly. [Upper right] CCM made of CCZ-EX® fixed on 3 points perfectly. [Lower right] CCM made of CCZ-EX® fixed on 3 points and one of them is perfectly.

References

[1] Araki, H., et al.: 2016, *Earth Planets Space*, **68**, 101.
[2] Otsubo, T., et al.: 2011, *Earth Planets Space*, **63**, e13-16.