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The research of a high emissivity spaceborne blackbody based on light capture

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ABSTRACT

The highly emissive spaceborne blackbody radiation sources are important devices for infrared value traceability by providing accurate infrared radiation to calibrate infrared loads. To meet the needs of the radiation calibration accuracy needed for infrared remote sensing, this paper proposes a highly emissive blackbody that uses a cubic reflection and absorption method based on light capture. An emissivity simulation based on ray tracing was carried out. The influences of specular reflection (SR), near specular reflection (NSR), and diffuse reflection (DR) on the emissivity of the blackbody were analyzed. Two blackbodies with NSR and DR were fabricated, simulated, and tested experimentally; the experimental and simulation results were consistent.

INTRODUCTION

With the development of infrared remote sensing technology, a high detection accuracy is required for infrared remote sensing loads. For example, when measuring climate change, the sea surface temperature needs to meet the measurement accuracy of 0.1 K and stability of 0.04 K decade^{-1} [1] . High emissivity spaceborne blackbody radiation sources are important devices for infrared value traceability by providing accurate infrared radiation to calibrate infrared loads.

Emissivity is an important indicator of blackbody. It increases if the structure of the blackbody supports it and if there is a high emissivity coating. The Cross-track Infrared Sounder (CrIS) [2] and Infrared Atmospheric Sounding Interferometer (IASI) [3] are currently the infrared remote sensing loads that have a high quantitative level on the orbit. The internal calibration source of the CrIS is a spectral trap blackbody with an emissivity of 0.995. The internal reference blackbody of the IASI is a cavity blackbody with an emissivity not less than 0.996. The spaceborne blackbody for the infrared hyperspectral atmospheric detector of the Fengyun-3E satellite is also a cavity blackbody and its emissivity can extend beyond 0.996 [4]. Previous studies have shown that it is difficult for the emissivity of spaceborne blackbody to reach the level of 0.999.

To meet the needs of the radiation calibration accuracy needed for infrared remote sensing, we proposed a highly emissive blackbody that uses a cubic reflection and absorption method based on light capture.

FUNDAMENTAL

The ideal optical path transmission model for the blackbody based on light capture (BBLC) after three absorptions and reflections is shown in Fig. 1. If the emissivity of surfaces A and B is ε, the specular reflectivity is (1-ε), and there is no diffuse reflection (DR) and near specular reflection (NSR); the normal emissivity of the blackbody ε_{normal} can be achieved:

$$\varepsilon_{normal} = 1-\left(1-\varepsilon\right)^3$$

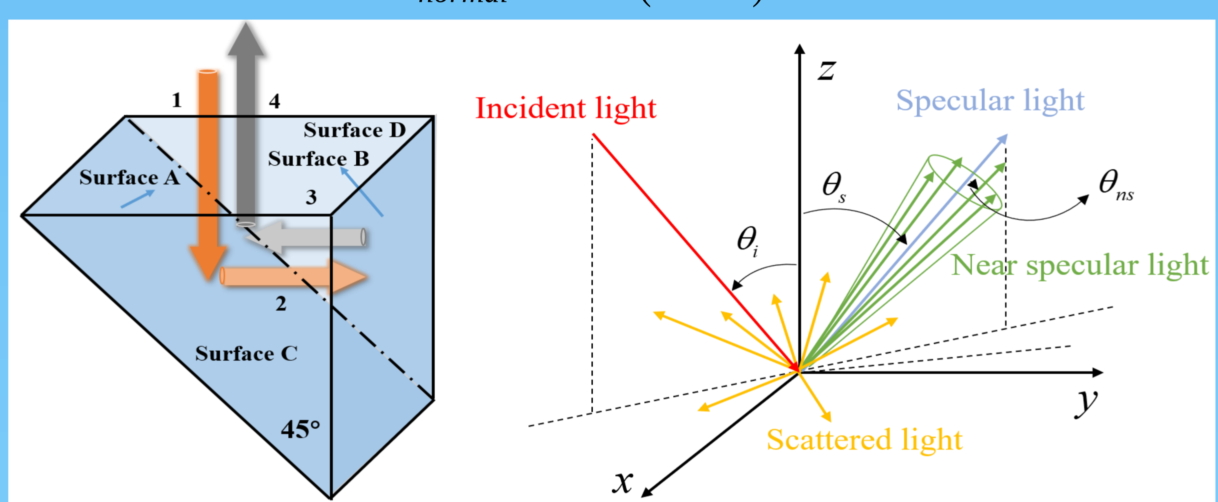

Fig. 1. Optical transmission model and three types of reflected light.

SIMULATION

A mechanical structure model of the blackbody was built and all the internal surfaces have the same reflection characteristics, as shown in Fig. 2(a). The emissivity at different positions of the aperture of the blackbody was simulated and the simulated locations of emissivity are shown in Fig. 2(b). The simulation parameter settings of the blackbody are shown in Table 1.

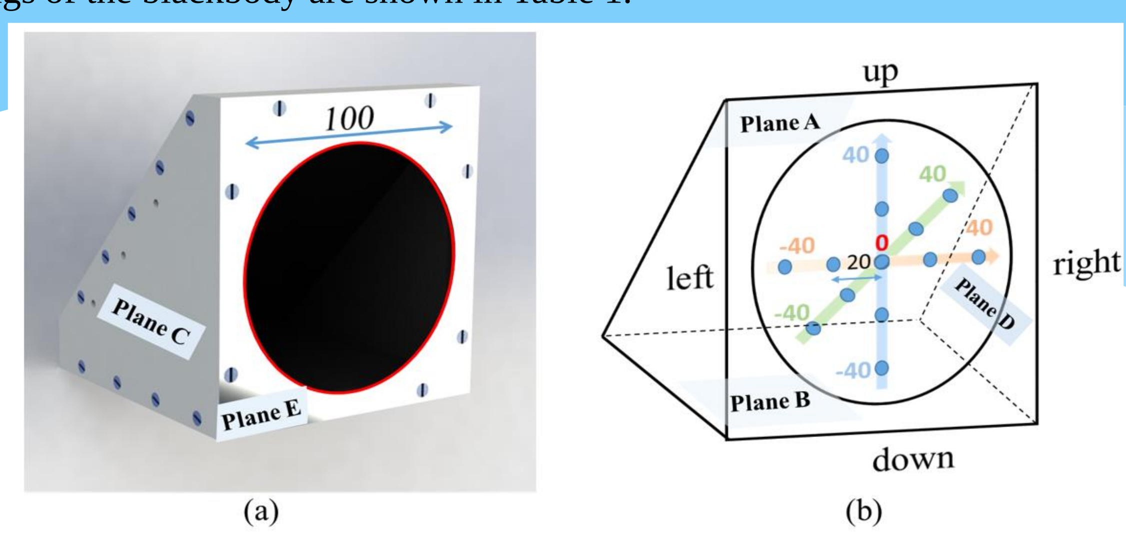

Fig. 2. Model of the blackbody and simulated locations of emissivity.

Table 1. Emissivity simulation settings of the blackbody.

Settings	Parameters
Internal surface characteristics of the blackbody	Emissivity: 0.90 ~ 1.00; interval is 0.02. Reflectivity: the total reflectivity includes SR reflectivity, DR reflectivity and NSR reflectivity; 50% DR means that the DR reflectivity is 50% of total reflectivity.
Light source	Position: As shown in Fig. 2 (b); Direction: Parallel light perpendicular to the cavity Power: 100 W; Radius: 4 mm.
Number of rays	1×10^6
Minimum power threshold	1×10^{-10} W

The simulation results shown in Fig. 3 indicated that the central normal emissivity of the blackbody could be improved by promoting the surface emissivity and reducing the DR proportion of the surface. From Fig. 4, for the three surface reflection settings, the directional emissivity uniformity was smallest with the 100% NSR.

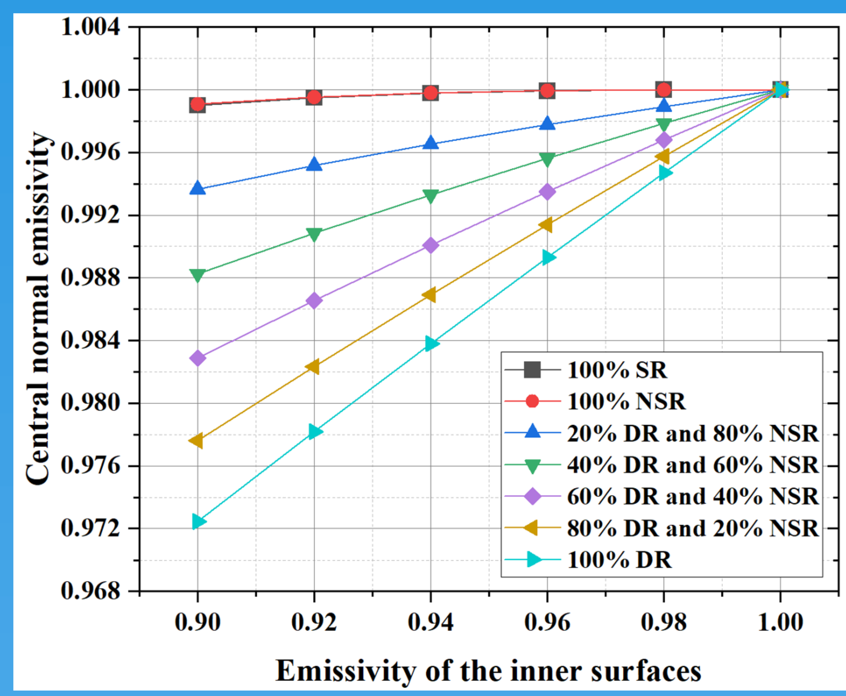

Fig 3. Normal emissivity at the center of the blackbody with different reflection types.

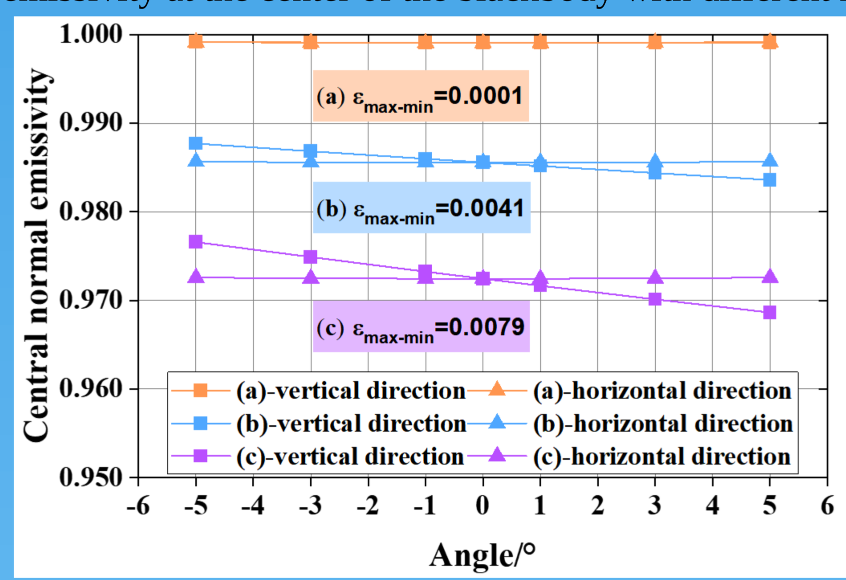

Fig. 4. Central directional emissivity at different angles.
(a) 100% NSR; (B) 50% NSR+50% DR; (c)100% DR.

The higher the NSR proportion of the surface was, the higher the overall normal emissivity of the blackbody was and the better the normal emissivity uniformity was. The results are shown in Fig. 5.

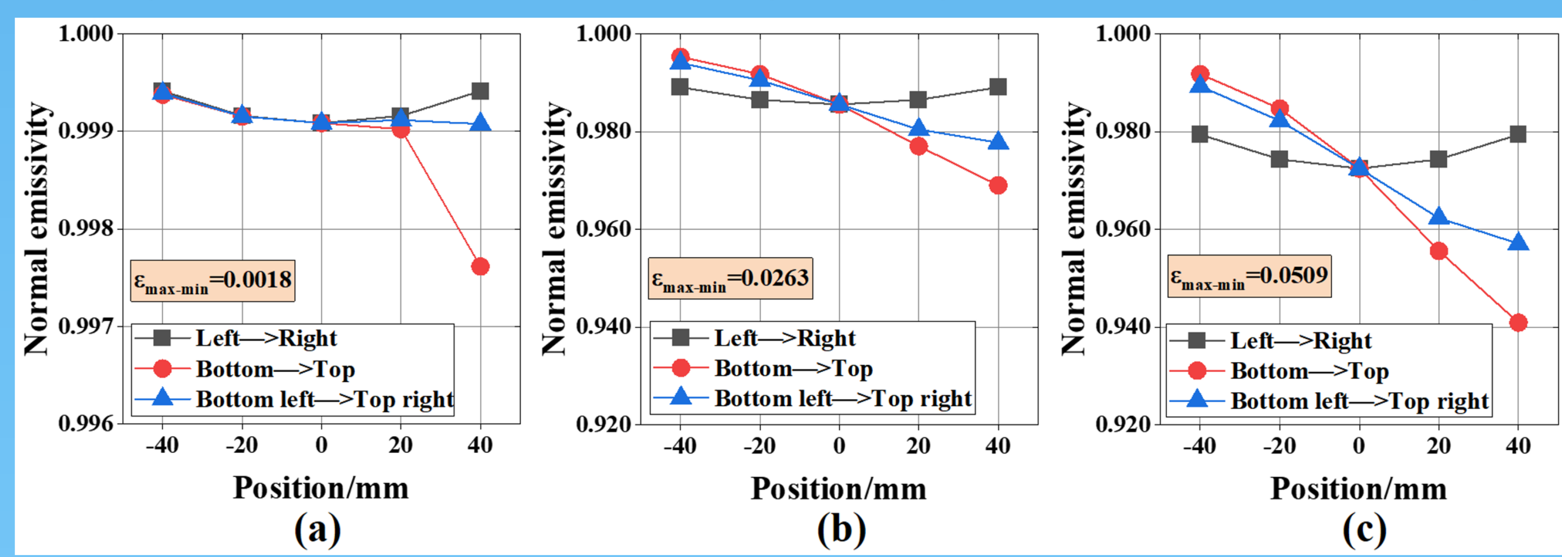

Fig. 5. Normal emissivity uniformity of the blackbody with different surface settings.

EXPERIMENT

Two blackbodies were fabricated and the waveband emissivity of 8~14 μm was measured. Both blackbodies' internal surfaces were oxidized and blackened after polishing. After that, the blackbody B was coated with high emissivity paint Nextel 811-21. Both blackbodies are shown in Fig. 6.

Fig. 6. Blackbodies with different surface treatments.

Table 2. Comparison between experimental and simulation results.

	Experimental results		Simulation results		Difference	
	A	B	A	B	A	B
Central normal emissivity	0.9988	0.9947	0.9991	0.9920	-0.0003	0.0027
Normal emissivity uniformity	0.0016	0.0088	0.0018	0.0153	-0.0002	-0.0065
Directional emissivity uniformity at small angles	0.0004	0.0002	0.0001	0.0014	0.0003	-0.0012

In case the structures of the blackbody were similar and they had same surface emissivity, the higher proportion of the NSR was, the higher the emissivity and the better the emissivity uniformity would be.

FUTURE WORK

The experimental and simulation results showed that the blackbody whose surface reflection component was NSR had a better light capture ability in the range of 8~14 μm, and it could achieve a higher emissivity and lower uniformity. The emissivity of the BBLC can reach 0.999 both in simulation and experiment, which can meet the application requirements. For future study, the emissivity of the blackbody in mid-wave infrared band could also be improved based on the principle of the BBLC. The surface coating material selection and surface treatment are reminded as our future works.

REFERENCE

1. G. Ohring, B. Wielicki, R. Spencer, B. Emery, and R. Datla. B. Am. Meteorol. Soc. 86(9), 1303–1314 (2005).
2. R. J. Glumb, D. C. Jordan, and J. P. Predina. Infrared Spaceborne Remote Sens. VIII. 4131, 108–119 (2000).
3. D. Blumstein, G. Chalon, T. Carlier, C. Buil, P. Hebert, T. Maciaszek, G. Ponce, T. Phulpin, B. Tournier, D. Siméoni, P. Astruc, A. Clauss, G. Kayal, and R. Jegou. Infrared Spaceborne Remote Sens. XII. 5543, 196–207 (2004).
4. C. Y. Hu, J. Q. Chang, X. P. Hao, J. Song, P. Wen, M. J. Gu, and L. Ding. Acta Metrol. Sin. 40(2), 232–239 (2019).

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