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Study of the Infrared Emissivity of Fixed-Point Blackbody Cavities

L. Hanssen, S. Mekhontsev, V. Khromchenko, A. Prokhorov, and J. Zeng

National Institute of Standards and Technology
Gaithersburg, Maryland 20899, USA

Abstract. We evaluate the infrared spectral emissivity of fixed-point cavities used in our infrared spectral radiance and sample emissivity measurement facilities. We compare Monte Carlo ray-trace modeling results of the cavity effective emissivity with measurement results of hemispherical reflectance. In addition, the cavity material reflectance properties are characterized for input to the model. Initial results for three cavity designs show quantitative and qualitative agreement depending on the design.

Introduction

NIST is developing facilities for the characterization of infrared spectral radiance[1] as well as the spectral emittance of materials. Both capabilities require a comparison of spectral radiance from the object to be characterized (source or sample) to that of one of a set of variable temperature blackbodies, using filter radiometers and the facility's Fourier transform spectrometer. The variable temperature blackbodies are calibrated in spectral radiance against a pair of fixed-point blackbodies with interchangeable crucibles of In, Sn, and Zn, and Al and Ag, respectively. Hence an accurate knowledge of the spectral emissivity of the fixed-point blackbodies is critical to the process. To obtain the emissivity, we combine the results of, ray-trace modeling and calculations, and measurements of directional-hemispherical reflectance (DHR), bi-directional distribution function (BRDF), and relative spectral emittance. A Monte Carlo ray-trace code is used to predict the cavity emissivity with input of the cavity shape and the emissivity and specularity of graphite, the cavity material. The reflectance measurements provide emissivity data of both the material and the cavity at room temperature. The results are used to compare with and validate the code results.

Fixed-point blackbodies

Fixed-point blackbody sources are used as reference points for temperature as defined by the ITS-90. In combination with Planck's law, these can provide a scale for absolute spectral radiance, which can, in turn, be used for the characterization of material emissivity as well as other blackbody sources. However, actual cavities employed in the fixed-point sources are never perfect blackbodies, but have spectrally dependent emissivity differing from 1 by variable amounts, in addition to possible non-isothermal temperature distributions. Generally, the emissivity of a blackbody cavitiy is determined through modeling using known values of the coating or wall material emittance. Because many materials used for blackbody cavities including graphite for fixed-point crucibles tend to have decreased emittance with increasing wavelength in the infrared spectral range, and because models always require the use of some assumptions of ideal behavior that cannot be exactly matched, we have endeavored to take a more comprehensive approach to the problem.

First, we have designed the fixed-point blackbodies to achieve the greatest degree of temperature uniformity within the restricted volume and for use up to a maximum viewing f/7 cone. The design was driven by the requirements of minimizing the size of source error while at the same time achieving high emissivity for a relatively large opening diameter of 7 mm. One implementation of the design using a Na heat pipe is shown in Figure 1.

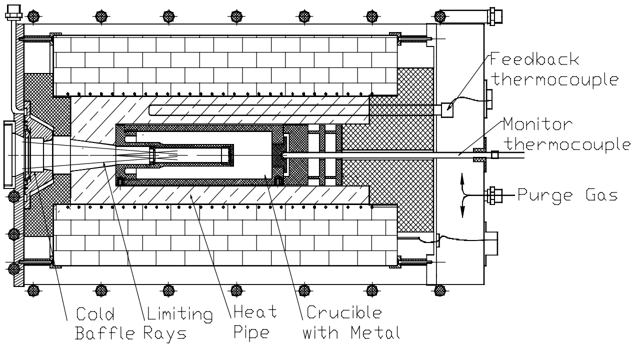

Figure 1. Fixed-point blackbody schematic for Al and Ag.

Additional details of the blackbody design can be found elsewhere.[1]

In the process of optimization, the fixed-point crucible has undergone several design changes. The most recent two designs, along with a traditional NIST design,[2] are shown in Figure 2. These three cavities are studied in this paper.

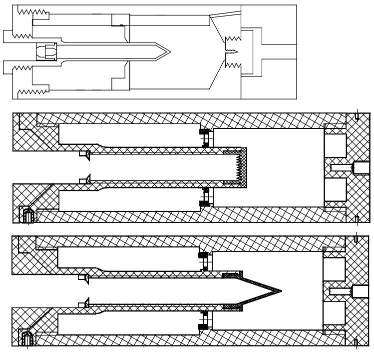

Figure 2. Three fixed-point cavities evaluated in this study.

The top design is the traditional one still in use today. The lower two are implementations of the designs described in Reference 1: the upper one with a v-grooved bottom and the lower with a cylindrical cone, although with a steeper angle than described in Reference 1.

Characterization Studies

We have measured the spectral DHR of the graphite crucible material from 2 to 18 µm. The scattering character of the reflectance was also examined. The results are shown in Figure 3, with a breakdown of reflectance into diffuse and specular components.

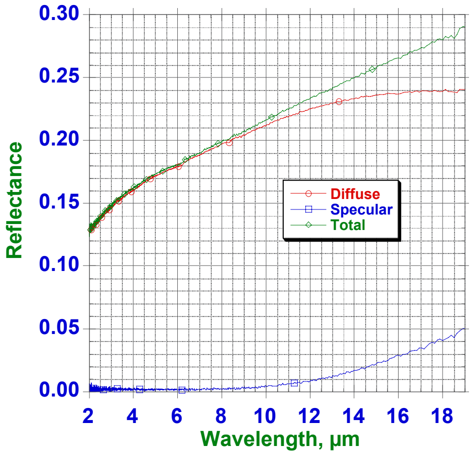

Figure 3. Reflectance of graphite used in the fixed-point crucible cavities.

The components of reflectance of the graphite have been used as one input a customized Monte Carlo ray-trace cavity modeling program to evaluate and predict the emissivity of the fixed-point cavities.[3] An analysis was made of all three designs. For the purposes of validation, a basic design of a cavity equivalent in size and shape to two in Figure 2, but with a simple flat bottom was also studied. An example result comparing the effective emissivity of three similar cavity designs, but with different bottoms is shown in Figure 4.

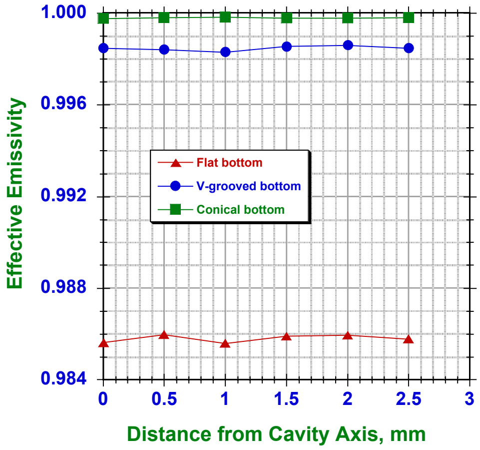

Figure 4. Model predictions of the effective emissivity of three fixed-point cavity designs.

It shows the radial variation of the emissivity for the three cases. The nominal effective emissivities are: 0.9997 for the cone bottom, 0.9984 for the v-grooved bottom, and 0.9857 for the flat bottom case.

For validation of the model results, we also performed measurements of the DHR of the cavities at 10.6 µm using a CO_2 laser and a small-entrance-aperture integrating sphere. The results of the DHR measurements were emissivities of: 0.9995 for the cone bottom, 0.996 for the v-grooved bottom, and 0.985 for the flat bottom case.

Discussion

We have reasonable agreement between the model and experimental results for the cone and flat bottom cavities, but less so for the v-grooved case. There are several factors that may account for the differences. These include the non-ideal construction of the v-grooved surface, as well as poor knowledge of the angular dependence of the graphite reflectance. We are addressing the issue of graphite data through a full characterization of the graphite BRDF at 10.6 µm, an example of which is shown in Figure 5. In addition, the Monte Carlo ray-trace program is being modified to incorporate the measured graphite BRDF results. We anticipate that these steps will lead to a better level of agreement and thus reduced uncertainties. We plan to extend our characterization efforts to the other BBs used in our spectral radiance measurement facilities.

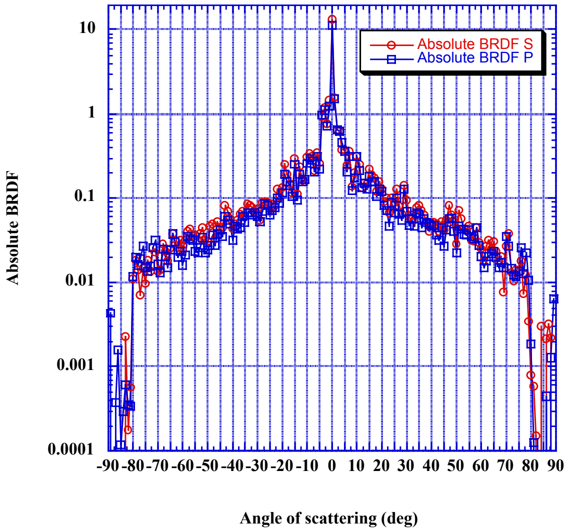

Figure 5. BRDF of a graphite sample at normal incidence.

References

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