Detector-based NIST-traceable Validation and Calibration of Infrared Collimators

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Abstract. We describe the detector-based validation of an infrared collimator at AFMETCAL using two non-imaging InSb radiometers centered at 3.4 µm and at 4.6 µm with 400 nm to 260 nm band-pass filters, respectively. The radiometers are calibrated in irradiance mode using detector-based radiometry at the NIST IR Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources (IR-SIRCUS) facility. The calibrated radiometers were then used to determine the irradiance at the output of the infrared collimator in an overfilled geometry, and the measured irradiances are compared to the calculated irradiances of the collimator. The differences of the calculated and the measured spectral irradiances were within the combined uncertainties of ~ 6 % (k = 2) over a range of temperatures from 450 °C to 1000 °C and various aperture sizes. The implementation of the NIST-traceable calibrations of the collimators results in total uncertainties of < 3 % (k = 2) in the infrared spectral irradiances.

Introduction

Collimators are used when sensors which radiometrically detect objects at a distance are calibrated for their irradiance responsivity. Since the optical design of the sensor is for use with collimated or low-divergence radiation, collimators are built to simulate the conditions under-use in the laboratory without requiring long object distances. Infrared collimators are critical components in the calibration procedures for many types of infrared sensors Typically, these collimators are constructed using a variable-temperature blackbody with a precision aperture and a collimating mirror.

Until now, the spectral irradiance from these infrared collimators has been determined only by using the knowledge of the individual component parameters such as the blackbody temperature and emissivity, the area of the aperture, the focal length and the spectral reflectance of the collimating mirror. The spatial uniformity of the mirror or mirrors and the atmospheric transmittance can also change the irradiance. Since the irradiance at the output of the collimator is calculated from the individual components, the total uncertainty of the irradiance depends upon measurements of the individual components and any increase in the uncertainties in the individual components could lead to increases in the final, total calculated irradiances.

An alternate approach to determining the irradiances from the collimators would be to use radiometers which do not rely upon the component characterizations. Since the radiometers are calibrated for spectral irradiance responsivity, the validation of the spectral irradiance could be performed by placing the radiometers in the collimated beam. The spectral irradiance scale for various collimators at physically different locations can be compared. We describe the development, the calibration and the use of such radiometers.

Radiometer Design and Calibrations

The InSb radiometers were constructed using a custom NIST design. The InSb detectors were constructed with precision 6.4 mm diameter apertures in front of 7 mm diameter InSb diodes. The cryogenic dewars are built with 17 ° field-of-view limiter to reduce the contribution from the room-temperature background radiation, and the spectral band-pass filters are also placed in the dewar and held at cryogenic temperatures. The InSb radiometers also constructed with the current-to-voltage converters attached to the back of the radiometer to increase the signal-to-noise ratios. The spectral irradiance responsivities of the InSb radiometers, which are shown in Fig. 1, were determined using the Electrical Substitution

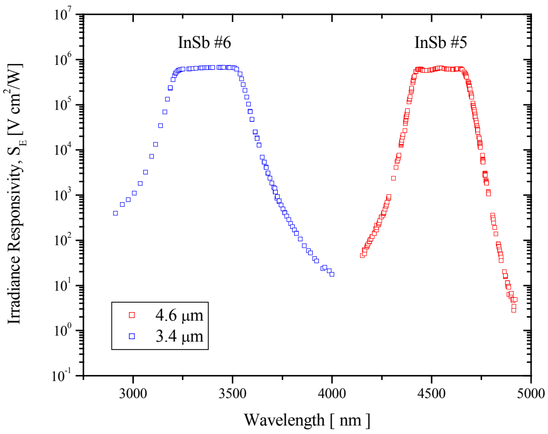

Figure. 1 The spectral irradiance responsivities of the InSb radiometers #6 (3.4 µm) and #5 (4.6 µm).

Bolometer in the IR-SIRCUS facility. The calibrations were performed with a laser-irradiated integrating sphere with a precision aperture to obtain a uniform irradiance at the plane of the entrance aperture of the InSb radiometers.

Spectral Irradiance Measurements

Due to the spectral width of the InSb radiometer spectral responsivities, the irradiance at the plane of the collimator opening can be obtained only with the knowledge of the temperature and the spectral emissivity of the blackbody at the focus of the infrared collimator. Since the irradiance responsivity, S_E, is measured, if the spectral irradiance of the source, E_λ is known then the irradiance response, v_C, can be calculated using,

$$v_C = \int S_E \cdot E_\lambda d\lambda \,. \qquad (1)$$

If the source at the entrance of the collimator is a blackbody at a temperature, T, with emissivity, ε, then

$$v_m = \int S_E \cdot E_\lambda = \tau \cdot \Omega \int S_E \cdot \varepsilon \cdot L_\lambda(T) d\lambda \,, \qquad (2)$$

where v_m is the measured voltage and Ω is the solid angle relating the radiance to irradiance and τ is the transmittance of the source setup. The transmittance factor accounts for diffraction losses, mirror reflectance losses and imperfect imaging of the collimating mirror. The band-averaged irradiance responses needed for the determination of the throughputs are shown in Fig. 2.

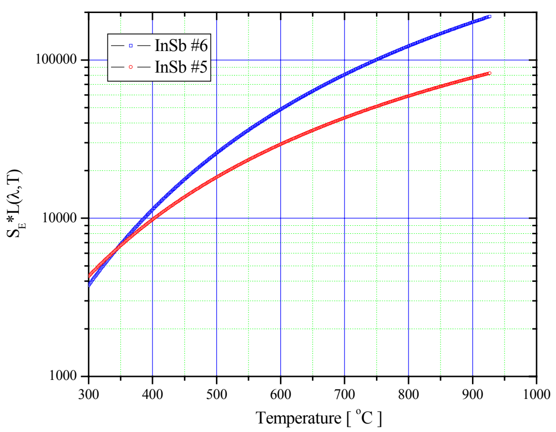

Figure 2. The calculated irradiance response using Eq. 1 for the respective InSb radiometers for a blackbody at the temperatures shown.

If the emissivity and the temperature of the blackbody at the source of the collimator is known, then the measured voltage, v_m, can be used in conjunction with the band-averaged radiance in Eq. 2 to determine the solid angle and the transmittance of the collimator. The knowledge of the transmittance, τ, and the solid angle, Ω, would specify the spectral irradiance averaged over the InSb #5 and InSb #6 wavelengths.

For a point source geometry, if the source has an area, A, then the solid angle is related to the distance from the source to the entrance aperture plane of the filter radiometer, d, by

$$\Omega = \frac{A}{d^2} \,. \qquad (3)$$

The solid angle term can be modified by additional factors such as the reflectance of mirrors if they are in the optical path from the radiance source to the irradiance measurement plane thus the solid angle in Eq. 3 is difficult to assess from the parameters of the collimator.

Comparisons with Source-based Irradiances

The InSb #5 and InSb #6 filter radiometers were used to measure the irradiances of a blackbody-based collimator at AFMETCAL. The measurements were performed with a chopper wheel placed between the opening of the blackbody and the aperture to reduce the influence of the background radiation. The signals from the radiometers were measured with a sine-wave measuring lock-in amplifier.

The comparisons reveal that under all measurements conditions, the source-based irradiance of AFMETCAL and the NIST detector-based irradiances are in agreement to < 6 % (k=2).

Further reduction in the AFMETCAL scale uncertainties can be realized by adopting the detector-based scale with the realizations as described in this work. NIST is working to improve the stability of the infrared lasers used in the IR-SIRCUS facility to reduce the total uncertainties to < 1 % (k=2).