Testing irradiance and radiance methods for absolute radiation thermometry based on InGaAs detectors in the NIR at CEM/CSIC

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Abstract. After measuring thermodynamic temperatures in the range from 900 °C to 2500 °C, The Centro Español de Metrología (CEM) in collaboration with the Instituto de Óptica of the Consejo Superior de Investigaciones Científicas (IO-CSIC) are currently involved in the measurement of thermodynamic temperatures down to 400 °C using radiometers based on InGaAs detectors with central wavelengths in the near-infrared spectral range (NIR). This communication summarizes the progress towards the extension of absolute radiation thermometry measurement range to lower temperatures.

1. Introduction
CEM’s set-up for the absolute calibration of filter radiometers in the visible wavelength range has been fully described in [1]. It is based on the radiance method and mainly consists of a supercontinuum laser source, a monochromator, an integrating sphere and a silicon trap detector. The measurement of radiation thermodynamic temperatures below the freezing point of silver (961.78 °C) implies the use of filter radiometers operating in the NIR, so this calibration set-up needs to be modified. Alternatively, the absolute calibration in spectral irradiance responsivity using large area Black Body sources (BBs) has been attempted in order to find out which calibration method could provide better results.

2. Design and calibration of the InGaAs transfer standard radiometer
A versatile housing, described in [2], was designed for its use on either possible absolute calibration methods, radiance or irradiance. For both approaches, a transfer standard detector calibrated in radiant flux against an electrical substitution cryogenic radiometer in the NIR and a precision aperture in front of the detector are required.

The detector chosen for the transfer standard is a windowless G8370-10NA InGaAs photodiode from Hamamatsu Photonics, with an active area of 10 mm in diameter. The homogeneity of these detectors and the possibility of operating in trap configuration was studied in [2]. Unlike silicon photodiodes, signal to noise ratio was worse for trap configuration compared to a single detector due to intrinsic InGaAs detectors’ characteristics such as their shunt resistance and reflectance. Therefore, trap configuration was discarded.

On the other hand, the use of a single InGaAs detector at normal incidence involves the possibility of back reflections from the detector reaching the aperture or the interference filter and being redirected back to the detector. In order to avoid this, a single photodetector can be mounted in the housing tilted 45° respect to the optical axis. This configuration reduces slightly the responsivity of the detector and, more important, introduces the issue of the influence of the degree of polarization from the radiation
source on its responsivity, since reflectance of sensitive surface depends on polarization state. Therefore, special caution must be taken comparing measurements from different sources.

The housing described in [2] also allows to place an interference filter in front of the InGaAs detector in order to operate in irradiance mode. The interference filter chosen for irradiance mode is a FBH1550-12 from Thorlabs with a central wavelength of 1.55 \( \mu \text{m} \) and a bandwidth of 12 nm. Its transmittance has been measured from 1500 nm to 1600 nm with a 1 nm bandwidth and a sampling step of 1 nm in a Perkin Elmer Lambda 1050 spectrophotometer applying the cascading (step-down) technique. Figure 1 shows the result for the averaging of three measurements. It was possible to confirm that the filter’s transmittance in the out of band region is five orders of magnitude lower than in the peak transmittance region.

![Figure 1. FBH1550-12 band-pass filter measured transmittance.](image)

In a preliminary approach, the calibration of the InGaAs detector responsivity has been done by comparison against an electrically calibrated pyroelectric radiometer in two different facilities: one based in a lamp-monochromator source and the other using a tunable laser at different wavelengths from 1540 nm to 1600 nm. Figure 2 shows the power responsivity calibration results obtained in both facilities.

![Figure 2. CEM InGaAs standard power responsivity measured with monochromator + lamp and with a diode laser with the detector normal to the incoming beam.](image)

The correction factor to be applied because of the spatial distribution of the radiation on the chopper blade plane is simpler to estimate for the tunable laser than for the lamp-monochromator source. However, the uncertainty in absolute responsivity with this pyroelectric detector is \( \cong 1\% \) which means...
an uncertainty of 0.5 °C at 400 °C and 1 °C at 1000 °C. An absolute calibration against a cryogenic radiometer is going to be performed over the next months.

3. Set-up for the radiance method

Figure 3 shows the set-up developed for the absolute radiance responsivity calibration of a commercial radiation thermometer (KE LP5), equipped with an InGaAs detector, to measure thermodynamic temperatures in the range from 419 °C to 1100 °C. A similar set up has been previously described in [3].

The radiating element of this facility is a supercontinuum (SC) laser from NKT Photonics, model SuperK EXR20, with a typical total power of 8 W, working in feedback mode with power stability better than 0.01%. A dispersive prism is used to reduce the power and preselect the light spectrum entering the monochromator. The diffraction grating used at the monochromator for this calibration has 900 grooves/mm. The entrance and exit slits widths of the monochromator are set to 0.9 mm resulting in a 1 nm full width at half maximum.

![Figure 3](image)

Figure 3. Set-up used to absolute calibration of LP5 by comparison with the InGaAs standard.

An InGaAs detector is placed at the monitor port of the integrating sphere for the power stabilization of the SC laser. The radiance-meter used is similar to the one described in [1] but with the standard InGaAs detector described in paragraph 2 mounted on a computer controlled translation stage. The maximum signal to noise ratio obtained for the LP5 is 10^3.

Preliminary results using the calibrated InGaAs transfer standard give a temperature of 962.55 °C for the Ag fixed point and 420.27 °C for the Zn fixed point. It is reasonable to assume these results will be improved after calibration of the InGaAs standard against the electrical substitution cryogenic radiometer.

4. Irradiance method measurements

The set-up shown in figure 4 can be used to measure the absolute radiation temperature of large aperture blackbodies in the range from 400 °C to 1100 °C applying the irradiance method. The InGaAs transfer standard in filter radiometer configuration described in section 2 and a precision aperture at the front of the blackbody have been used to calculate directly thermodynamic temperatures from the irradiance measurement by using the throughput of the system.
Both apertures are centered in place along the optical path using a double laser alignment system and the distance between them, roughly 1 meter, is measured with a MITUTOYO 137-204 tubular inside micrometer. The diameter of the apertures and the micrometer are calibrated by CEM dimensional laboratory.

The signal measured in this set up by the InGaAs detector at the Zinc point remains too close to the noise level, insufficient for a correct thermodynamic temperature calculation.

5. Discussion and conclusions
Several options have been tested at CEM/CSIC for extending the measurement range of thermodynamic temperature down to 400 °C. New InGaAs transfer standards have been developed and currently they are going to be used to calibrate a commercial radiation thermometer or directly as a standard filter radiometer.

As other authors have also pointed out, the use of InGaAs photodiodes as transfer radiometers instead of silicon ones, introduces new issues such as less surface homogeneity, lower signal to noise ratio and lower shunt resistance, that can influence the measurement method or the amplification of the signal. Avoiding inter-reflections by rotating the photodiode results in having to consider the degree of polarization of the incident radiation as a new source of uncertainty.

Both radiance and irradiance methods can be used to obtain the thermodynamic temperature in this range. Main issue here is to get enough signal to noise ratio in the commercial radiation thermometer and in the InGaAs filter radiometer.

As an alternative approach, the calibration at 1.55 μm could be based in the one done at 650 nm using a pyroelectric detector with a flat spectral response as transfer standard.

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