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A Radiation Thermometer based on an InGaAs-Photodiode at 1.6 µm for Temperatures down to 80 °C

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Summary:

In the last decade the specific detectivity of InGaAs-photodiodes has improved significantly. Hence, the lower detection limit of InGaAs-photodiode based radiation thermometers at 1.6 µm can be extended. Here, an existing radiation thermometer was equipped with a state-of-the-art InGaAs-photodiode. The radiation thermometer was characterized and calibrated and a reference function has been compiled. The lower temperature limit could be extended from 150 °C down to 80 °C.

Keywords: Radiation Thermometer, InGaAs-Photodiode, Characterization, Reference Function

Introduction

The working group "Infrared Radiation Thermometry" of the Physikalisch-Technische Bundesanstalt (PTB) provides non-contact temperature measurements in the range from -170 °C to 962 °C at the highest metrological level. High-quality infrared radiation thermometers are used as transfer instruments as well as for comparison measurements. InGaAs-photodiode instruments are superior to instruments based on thermal detectors in terms of temporal stability and achievable measurement uncertainties in the short wavelength range. However, the operating wavelength around 1.6 µm limits the minimal detectable temperature of InGaAs-radiation thermometers to typically 150 °C to 200 °C. In the last decade, the performance of InGaAs-photodiodes increased by several orders in magnitude in terms of specific detectivity. By using a commercial two-stage cooled InGaAs-photodiode, the minimal detectable temperature of a 15 years old lens-free radiation thermometer (LF-IRRT2) was improved from 150 °C to 80 °C.

Design of the Radiation Thermometer

The InGaAs-photodiode has an active area of 5 mm in diameter and is operated at a temperature of approximately -20 °C ± 0.005 °C to reduce the wear and tear of the TE-cooler. The temperature is controlled by a custom-built temperature controller. The controller housing also includes a custom-built transimpedance amplifier, tailored for the photodiode. Gains can be set from 10^5 to 10^{10}. An additional voltage gain factor of 10 can be set at every gain to increase the signal level. By means of a so-called reference function [1] the output signal is converted into a temperature reading. The reference function is given by:

$$i = \frac{A_1 \cdot A_2}{D^2} \int_{\lambda_1}^{\lambda_2} L_\lambda(\lambda, t_{90}) \cdot s(\lambda) \cdot \tau(\lambda) \cdot d\lambda \qquad (1)$$

with the photocurrent i, $A_{1,2}$ the active areas of a aperture stop and field stop, $\lambda_{1,2}$ the limiting wavelengths, $L_\lambda(\lambda,t_{90})$ the spectral radiance of the blackbody at the temperature t_{90}, $s(\lambda)$ the spectral responsivity of the photodiode and $\tau(\lambda)$ the transmission of the interference filter. Assuming a linear responsivity, the input values of Eq. (1) can be determined by measuring the photocurrent i at several known temperatures $t_{s,90}$ and applying a least square fit. In order to obtain a radiation temperature $t_{s,90}$ from the photocurrent i, the temperature is inversely calculated by comparing the measured photocurrent with the photocurrent according to Eq. (1). Figure 1 shows a cut presentation of the LF-IRRT3.

Tab. 1: Specifications of the LF-IRRT3

Component	Nominal value
Aperture stop Ø	6.00 mm
Field stop Ø	3.71 mm
Distance aperture stop to field stop	243.8 mm
Detectivity (data sheet)	6.7×10^{13} cmHz$^{1/2}$/W
Bandpass of filter	1.55 µm - 1.65 µm
Maximum transmission of filter	81% at 1.6 µm

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The main parts are a water-cooled detector housing (1) including an interference filter and the field stop, a set of stray light baffles (2) in a water-cooled housing, a motorized optical shutter (3) and a (4) water-cooled front aperture (aperture stop) with additional heatshield.

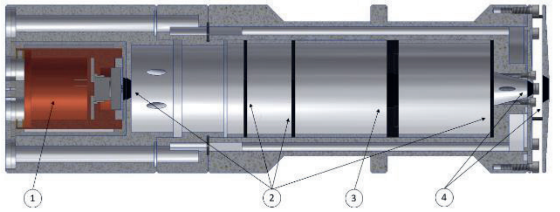

Fig. 1 Cut presentation of the InGaAs-radiation thermometer LF-IRRT3. The parts are listed in the text.

Calibration of the LF-IRRT3

The LF-IRRT3 has been calibrated at the Thermal Imager Calibration Facility (ThermICF) [2] (see Figure 2) of PTB. The ThermICF covers the temperature range from -60 °C to 962 °C by means of heatpipe blackbodies. Additional large area surface radiators are available in the temperature range from -15 °C to 500 °C for the full field of view characterization of thermal imagers. The photocurrent of the LF-IRRT3 was measured at several temperatures in the range from 80 °C to 960 °C and the input parameters of Eq. (1) were determined. The LF-IRRT3 together with the read-out electronics (transimpedance amplifier and digital multimeter) was treated as a “blackbox”, i.e. only the radiation temperature $t_{S,90}$ and the photocurrent i were used for the calibration. In the observed temperature range the photocurrent increases from ≈10^{-14} A to ≈10^{-6} A. Hence, the full gain range of the transimpedance amplifier has to be used. The gain ratios were determined at four different temperatures to allow an overlap of different gain settings. To simplify the evaluation of the radiation temperature, an approximation of Eq. (1):

$$i = c \cdot \int_{\lambda_1}^{\lambda_2} L_\lambda(\lambda, t_{90})\, d\lambda \qquad (2)$$

with $c = A_1 \cdot A_2 \cdot \tau_0 \cdot s_0 / D^2$ is used. The resulting parameters are given in Table 2. The resulting temperature difference $t_{\text{Instrument}}$-$t_{s,90}$ according to Eq. (2) is given in Figure 3.

Tab. 2: Input parameters of Eq. (2) obtained by the calibration of LF-IRRT3 against high-quality heatpipe blackbodies of PTB

Parameter (see text)	Value
Instrument const. c	$4.040989 \cdot 10^{-9}\ \text{Am}^2\text{srW}^{-1}$
wavelength limit λ_1	$1.542945 \cdot 10^{-6}\ \text{m}$
wavelength limit λ_2	$1.645718 \cdot 10^{-6}\ \text{m}$

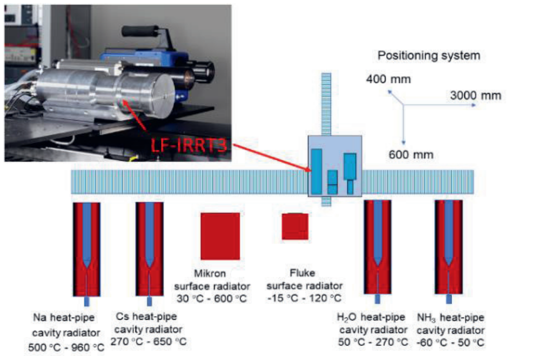

Fig. 2 Schematic of the Thermal Imager Calibration Facility (ThermICF) of PTB. The facility uses four heatpipe blackbodies to provide radiation temperatures traceable to the ITS-90. The LF-IRRT3 is shown mounted on a long-range x-y-z-translation system in front of the heatpipe blackbodies and the surface radiator. The inserted photograph shows the LF-IRRT3 together with a transfer radiation thermometer and a thermal imager

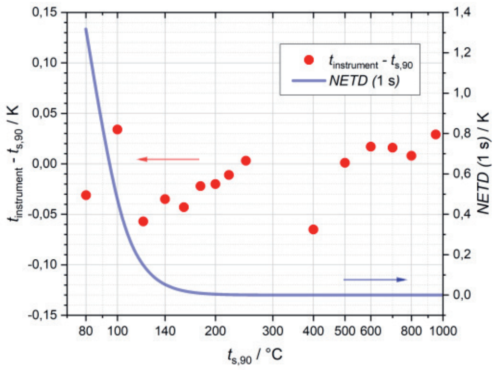

Fig. 3 Difference of the measured radiation temperature $t_{\text{Instrument}}$ of the LF-IRRT3 and the radiation temperature $t_{s,90}$ of the blackbodys (red dots) and the noise equivalent temperature difference (NETD) of the LF-IRRT3 (blue curve) for 1 s integration time

Conclusion

The LF-IRRT3 was developed on the bases of a state-ot-the-art InGaAs-photodiode and calibrated against the high-quality heatpipe blackbodies of PTB. The difference $t_{\text{Instrument}}$-$t_{s,90}$ is below 65 mK and within the expanded uncertainties of the blackbodies for all observed temperatures. However, the necessary integration time increases from 1 s for temperatures above 120 °C to approximately 5 minutes at 80 °C.

References

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