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Absolute Mid-infrared Spectral Responsivity Scale Based on Thermal Detectors and the Cryogenic Radiometer

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Abstract

The Physikalisch-Technische Bundesanstalt (PTB) has extended its capability for the realization and dissemination of the absolute spectral responsivity of thermal detectors from the near-infrared into the mid infrared (MIR) wavelength range. The calibration method relies on the application of a large area, multi-junction thin film thermopile detector as a transfer standard, characterized with two independent approaches in terms of its MIR spectrally flat (in a word: grey) relative spectral responsivity. The required SI traceability is achieved through absolute calibrations in the wavelength range from 1.5 µm to 2.4 µm against the PTB national detector standard, the cryogenic electrical substitution radiometer. In combination with an upgraded MIR dedicated spectral comparator setup, this allows the measurement and dissemination of the spectral responsivity up to a wavelength of 5 µm with relative standard uncertainties below 2 %.

Key words: spectral responsivity, mid-infrared, thermopile detector, SI traceability, calibration

Introduction

The MIR (3 µm – 50 µm) is a spectral region of increasing interest as it contains the atmospheric spectral windows for remote sensing (e.g. 3 µm – 5 µm for wildfire detection) [1] and the wavelengths of vibrational signatures of climate relevant atmospheric molecules [2]. Together with the recent developments in the detector and source based MIR instrumentation, e. g. quantum cascade lasers as practical and versatile tunable MIR wavelength sources [3], this gives rise to a large number of applications requiring high-accuracy radiometric SI traceability in this wavelength range.

Currently, only very few national metrology institutes (NMIs) are able to provide this service. To meet the needs in this field, the PTB as the German National Metrology Institute has set up new, dedicated methodologies and facilities to realize and disseminate the MIR absolute spectral responsivity.

Method

The well-established method for the dissemination of the continuous spectral responsivity in the UV, VIS and NIR spectral range is based on quantum detectors, their absolute calibration at discrete wavelengths and an interpolation over the applicable wavelength range with a physical model or – if the separation between the discrete wavelengths is small enough – with a mathematical model. However, the situation in the MIR is different. The physical models for usual photon detectors are not accurate enough and an interpolation by a mathematical model requires a tremendously large number of absolute calibrations against the cryogenic electrical substitution radiometer to cover the entire MIR wavelength range.

Therefore, the PTB chosen method for the realization and dissemination of the absolute spectral responsivity in the MIR is based on a thermal detector – serving as transfer detector – with a spectrally flat and accurately characterized relative spectral responsivity, followed by an absolute calibration against the national primary detector standard, the cryogenic electrical substitution radiometer.

Transfer detectors

A set of three thin film thermopile detectors (TPD) of the type TS-76, manufactured by the Leibniz-Institut für Photonische Technologien e.V. (IPHT) Jena [4], were selected to be used as possible MIR spectral responsivity transfer detectors. These multijunction TPDs are based on 76 BiSb/Sb-thermocouples and have a sensitive area of 7 mm in diameter with a silver black thermal absorbing layer. The batch investigated consisted of two windowless specimens and one specimen with a CaF_2-

window and a Xe gas filling (Fig. 1). Depending on the variant, the spectral responsivity of the TPDs varies from about 3.5 V·W^{-1} (windowless) to about 9 V·W^{-1} (with window). The TS-76 TPDs exhibit a comparatively short time constant for this type of detector of about 0.5 s (windowless) or 1 s (with window and gas filling). The NEP is less than 2 nW·Hz$^{-1/2}$ for the window-equipped type, the latter increasing by a factor of 3 for the windowless version.

Fig. 1. TS-76 multijunction thin film thermopile detector, version with CaF_2 window and Xe gas filling (photo: IPHT Jena)

Relative spectral responsivity characterization

The spectral properties of the thin film TPD absorbing layer were characterized with two independent methods.

In order to identify eventual spectral features of the absorbing layers of the TPDs, the reflectivity of all three specimens of the batch has been determined at the PTB setup for directional reflectance measurements [7] in the wavelength range from 1 µm to 25 µm. The results of the measured reflectance for the relevant MIR wavelength range from 1 µm to 6 µm are depicted in figure 2.

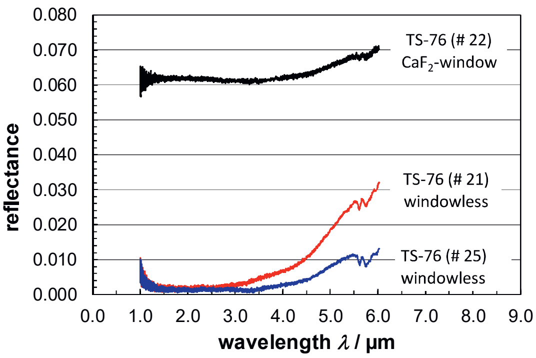

Fig. 2. Near normal incidence (12°/12°) spectral reflectance of the absorbing layer of thin film thermopile detectors TS-76

For two TPDs, labeled as # 22 (CaF_2-window) and # 25 (windowless) in the graph, no significant change of the reflectance with respect to wavelength was found in the range from 1 µm to 4 µm, solely in the range from 4 µm to 5 µm a slight increase of about 1 % was observed. As expected, the TS-76 TPD # 22 has an overall higher reflectance than the windowless versions due to the CaF_2-window used. One of the windowless TPD (# 21) displayed a comparatively larger reflectance increase with wavelength up to 3 %. On the basis of these results, the TS-76 TPDs # 22 and # 25 were selected for the subsequent measurements.

The second method applied for the relative responsivity characterization of the TS-76 thin film TPDs consisted in a comparison of the latter with a cavity type TPD at the PTB spectral comparator facility.

The cavity TPD used for the comparison is of the type PP1 manufactured by VNIIOFI, Russia [5, 6]. Due to its double cavity design and the compensation operating principle (Fig. 3), the influence of external temperature variations can be considered as negligible. Additionally, the cone shaped design of the cavities in conjunction with the AK-243 matt-black paint coating leads to a constant cavity absorptivity within 10^{-4} over a wide spectral range from 0.4 µm to 15 µm. The main detriments are its relatively large time constant of about 5 s and the comparatively low responsivity of 1 V·W^{-1} leading to time consuming measurements and hence making the PP1 TPD less suitable for routine calibrations. Yet, this type of detector can be very well applied for the investigation of the spectral properties of fast, thin film TPDs.

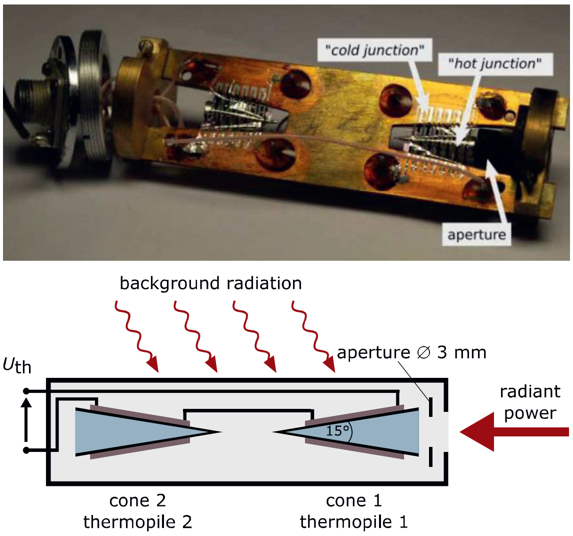

Fig. 3. Compensated, cavity type thermopile detector PP1 from VNIIOFI [5, 6)] (housing removed) and the schematic view of the underlying operating principle.

Prior to the comparison, the applied spectral comparator facility (SCF) underwent a major upgrade in terms of its MIR applicability. A schematic overview of the improved setup is given in figure 4, a comprehensive presentation of the SCF and its operation principle can be found in [8, 9].

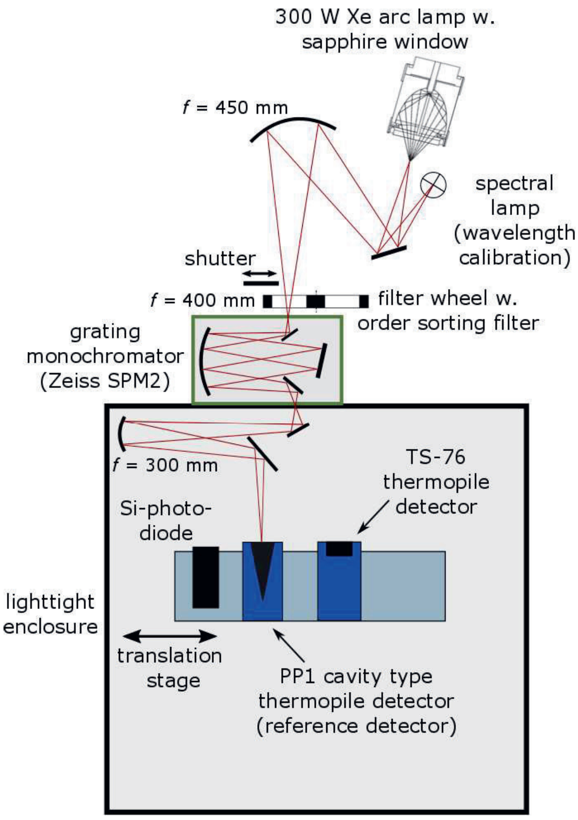

Fig. 4. Schematic view of the Spectral Comparator Facility of PTB, upgraded for spectral calibrations and radiometric characterizations of detectors in the mid-infrared (MIR) spectral range (2 µm – 6 µm)

Beside the extension of the wavelength range of the setup in the MIR up to 6 µm through the integration and accurate wavelength calibration of two selected monochromator gratings, the focus on the upgrade was set in obtaining a high MIR spectral flux in the sensor plane of the TPDs. This objective was achieved primarily by the implementation of a 300 W, sapphire window Xenon arc lamp as a MIR radiation source. In the wavelength range from 1.5 µm to 5 µm, this type of arc lamp has a spectral distribution corresponding to a blackbody operating at 6000 K. Additionally, to improve the overall MIR transmittance of setup, the existing SCF optics was replaced by an MIR optimized gold coated mirror optics. The available spectral flux as a function of the applied grating is listed in table 1 for representative wavelength values.

The comparison of the TPDs TS76 and PP1 was performed in flux mode i.e. the exit slit of the monochromator was imaged in a ratio of 1:1 onto the detectors under-filling the respective sensitive areas. The detectors were mounted in dedicated housings which were temperature controlled within ± 0.1 °C via external water thermostats. During the measurement, the temperature of the housings was monitored with the integrated Pt100 temperature sensors.

Tab. 1: Spectral flux in the MIR wavelength range at the PTB Spectral Comparator Facility (SCF)

grating number	spectral bandwidth (FWHM) / nm	wavelength / µm	radiant power / µW
1	12	2	10
		3	3.5
2	24	3.5	15
		5	3.5

The alignment of the detectors on the translation stage with respect to the optical axis of the setup was done with kinematic rotation / translation stages. The signal voltage of the TPDs was amplified by two individual, impedance matched and adjustable offset amplifiers. To consider a possible drift of the TPDs dark signals during the measurement procedure, the corresponding dark signals were measured accordingly utilizing a shutter. In order to minimize the effect generated by the heating-up of the shutter blade due to the high-power optical radiation source and hence acting as a radiation source towards the entrance slit of the monochromator, the shutter used was of a double bladed design.

The measured signal ratio of the thin film TPD TS-76 # 25 and the cavity type TPD PP1 in the wavelength range from 2 µm to 5 µm is shown in figure 5. Within the standard uncertainty of the ratio measurement, the thin film TPD can be considered as a “spectrally flat” detector in terms of its relative spectral responsivity within ±1 %.

Absolute spectral responsivity

Finally, the absolute spectral responsivity of the thin film TPD has been measured by comparing the TPD voltage signal with the absolute radiant power which has been measured traceable to the SI by using a cryogenic electrical substitution radiometer, which is PTB's national detector standard. The measurements have been performed in the wavelength range between 1.5 µm to 2.4 µm by using the radiation of a supercontinuum laser which was monochromatized with a prism-grating double monochromator (Fig. 6).

This absolute calibration complements the relative measurements performed at the PTB spectral comparator facility. The measurements confirm the spectral flatness of the TPD in the wavelength range 1.5 µm to 2.4 µm within an uncertainty of about 1% (Fig. 7). The absolute responsivity value is about 3.75 $V{\cdot}W^{-1}$ which is in the expected range for a windowless TS-76.

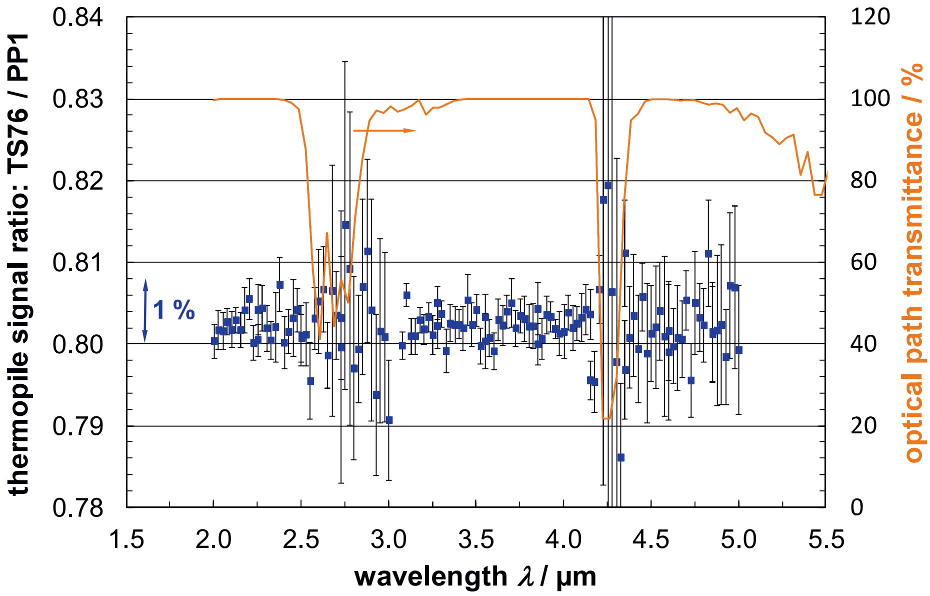

Fig. 5. Measured signal ratio of the thin film TPD TS-76 and the cavity type TPD PP1 (left scale). The error bars denote the standard uncertainty. The optical path transmittance at the PTB spectral comparator for standard atmospheric conditions is also shown to illustrate the origin of the increased noise at 2.7 µm / 4.2 µm, (right scale)

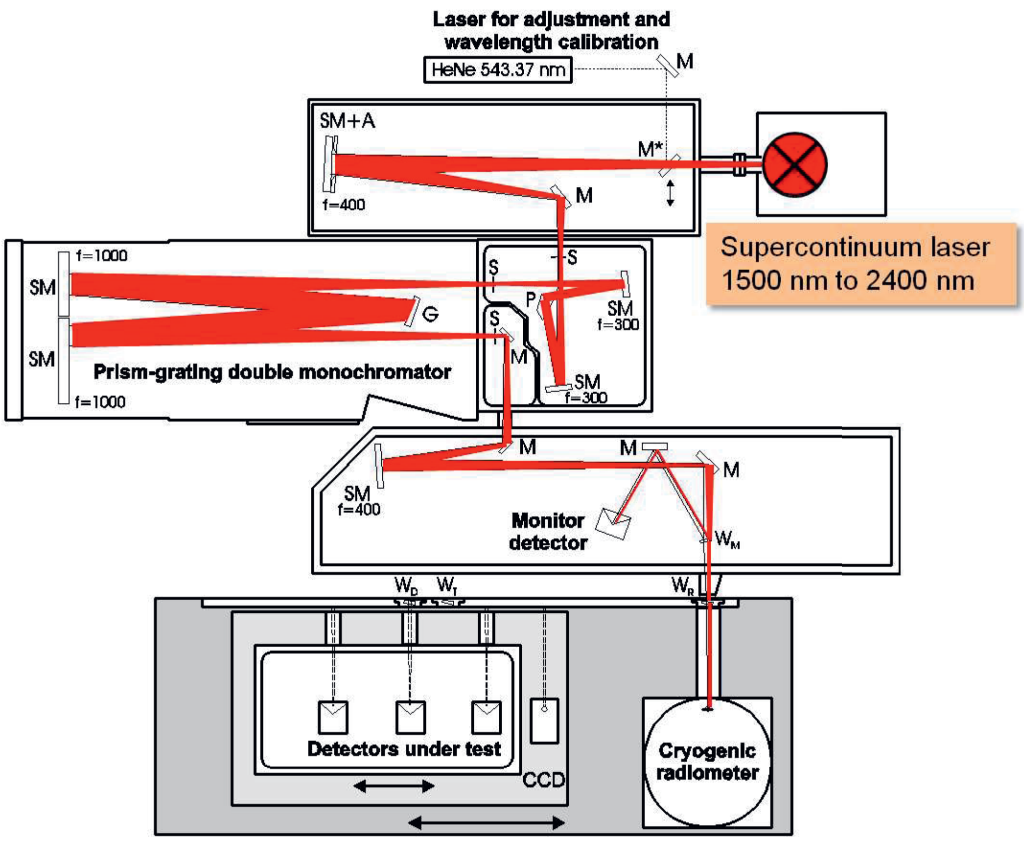

Fig. 6. Setup for the measurement of the absolute spectral responsivity of the thin-film thermopile TS-76 applying the PTB national detector standard for the measurement of radiant power, the cryogenic radiometer with a supercontinuum laser as the optical radiation source.

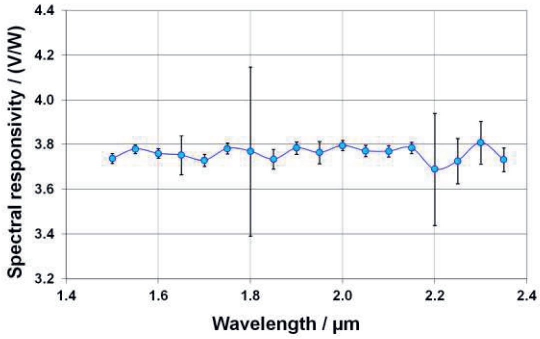

Fig. 7. Spectral responsivity of a thin film thermopile detector TS-76 measured against a cryogenic radiometer in the range 1.5 µm to 2.4 µm.

Disclaimer

The component producers/suppliers are mentioned for identification purposes only. Such identification does not imply recommend-dation or endorsement by the PTB nor does it imply that the producers/suppliers identified is necessarily the best available for the purpose.

References

[1] R. S. Allison et al, *Sensors (Basel)* 16(8): 1310.(2016); doi: 10.3390/s16081310

[2] L. S. Rothman, *Journal of Quantitative Spectroscopy and Radiative Transfer* 130, 4-50 (2013); doi: 10.1016/j.jqsrt.2013.07.002

[3] *Nature photonics* 6(7), 407-498 (2012); doi: 10.1038/nphoton 2012.164

[4] E. Kessler, *Innovationen in der Mikrosystemtechnik* 26, 107-114 (1995)

[5] V. I. Sapritskii, M. N. Pavlovich, *Metrologia* 26, 81-86 (1989); doi: 10.1088/0026-1394/26/2/001

[6] S. P. Morozova et al, *Metrologia* 28, 117-120 (1991); doi: 10.1088/0026-1394/28/3/002

[7] M. Kehrt, C. Monte, *13th International Conference on Infrared Sensors & Systems* 121-123 (2013)

[8] R. Friedrich et al, *Metrologia* 32, 509-513 (1995/96); doi: 10.1088/0026-1394/32/6/22

[9] D. R. Taubert et al, Metrologia 40, 35-38 (2003); doi: 10.1088/0026-1394/40/1/309