Measurement of the absorptance of a cryogenic radiometer cavity in the visible and near infrared (NIR)

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Abstract. Results of the measurement of the absorptance of a LaseRad cavity used as an absorber in the cryogenic radiometer in the Physikalisch-Technische Bundesanstalt (PTB) are presented. The measurements were carried out at several laser wavelengths in the visible and near infrared (NIR); at 633 nm, 1280 nm - 1360 nm and 1480 nm – 1620 nm. The absorptance of 0.999885 ± 3.0 × 10^{-6} measured at 633 nm matches very well with the value of 0.999879 ± 1.0 × 10^{-5} reported by the manufacturer (Cambridge Research & Instrumentation, Inc.) . In the NIR the absorptance is approx. 1.1 × 10^{-4} ± 3 × 10^{-6} lower than at 633 nm, which is significant for high accuracy measurements. In the wavelength range from 1280 nm to 1620 nm, the absorptance varies by 19 × 10^{-6} which is almost negligible for this wavelength range.

1. Introduction

In the last decade, the demand for calibration services in the field of optical communication through optical fiber had increased substantially and consequently also the need of lower measurement uncertainties. Therefore, the PTB and also other National Metrology Institutes (NMIs) work on transfer standards (Ge and InGaAs photodiodes) calibrated directly against the Cryogenic Radiometer (CR), the primary standard for optical power measurement, in the near infrared (mainly around 1300 nm and 1550 nm) [1-4]. Thus, uncertainties below 4×10^{-4} have been obtained in these wavelength ranges. In general, two correction factors contribute to the CR measurement accuracy: the non-ideal absorption coefficient α of the cavity and the non-ideal transmittance τ of the Brewster-angle window. Usually, the absorption coefficient at 632.8 nm reported by the manufacturer is used in the PTB and other NMIs and considered to be constant for other wavelength ranges [1-4]. However, to achieve lower measurement uncertainties, it is necessary to know the exact spectral distribution of both coefficients.

In this paper, we report the absorption coefficient measurements of the LaseRad cavity carried out at several wavelengths: 632.8 nm, 1280 nm – 1360 nm and 1480 nm – 1620 nm. The cavity under measurement was purchased by the PTB from the manufacturer of our CR, Cambridge Research & Instrumentation (CRI), separately for this purpose. It has the same characteristics as the cavity contained in the CR; it is constructed from an oxygen-free high-conductivity copper (OFHC) tube and blackened with Chemglaze Z-302 black paint [5].

2. Measurement method

The absorption coefficient of the cavity is determined from the measurement of the diffuse reflection ρ by the simple formula $\alpha = 1 - \rho$. The measurement is carried out using a four-ports integrating sphere and a photodetector (see Figure 1). In the visible wavelength range, a He-Ne laser operating at 632.8 is used as radiation source. The beam irradiates a 2-mm diameter circular aperture and is imaged 1:1 by a 200 mm focal length lens - passing through the sphere - into the cavity. To reduce the fluctuation of the laser power, an external stabilizer and a monitor detector are used. An attenuator and a polarizer are used to maintain the power level and the linear polarization of the laser beam. The detector placed on the sphere for the measurement at 632.8 nm is a Si detector of 5-mm diameter (Hamamatsu S1227 66BR). In the IR, two tunable diode laser sources (Agilent 81600B) were used, whose wavelength were adjusted from 1280 nm to 1360 nm and from 1480 nm to 1620 nm, respectively. The outputs of the laser sources are fiber-optic connectors; therefore an external collimator with a fiber-optic pigtail is used to collimate the laser beam. The laser stabilizer, used during the measurement at 632.8 nm, is not needed for the measurement in the IR, instead, the collimator was placed in front of the aperture and polarizer, see also Figure 1. An InGaAs photodiode (Telcom 35PD5M) of 5-mm diameter placed on the sphere carries out the measurement of the reflected fluxes.

The reflectance measurement of the cavity is done as follows: in a first step, a laser beam illuminates the cavity attached to the sample port. The reflected flux is diffusely emitted from the cavity and is collected by the integrating sphere finally generating a signal S_c is generated by the photodetector. In this scheme the white standard is attached to the supplementary port. In a second step, the cavity and the white standard interchange their ports from where a second signal is generated S_s. A third signal S_0 is measured by taking off the white standard from the sample port. From the ratio between those signals one can get the reflection coefficient of the cavity, ρ_c:

$$\frac{S_c - S_0}{S_s - S_0} = \frac{\rho_c}{\rho_s}\cdot\delta \;\rightarrow\; \rho_c = \frac{S_c - S_0}{S_s - S_0}\cdot\frac{\rho_s}{\delta} \tag{1}$$

where ρ_s is the reflection of the white standard and δ is the correction factor due to possible changes of the geometrical conditions of the sphere between the two measurement processes. In our case, these conditions remain unchanged, so $\delta = 1$.

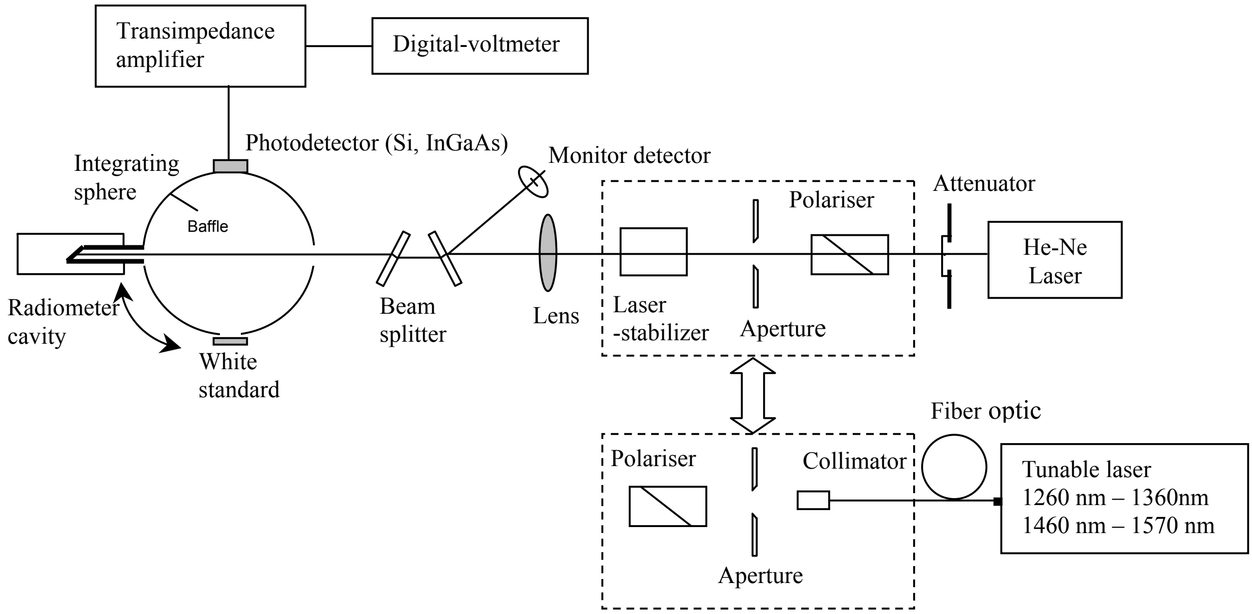

Figure1. Experimental set-up used to measure the diffuse reflectance of the radiometer cavity.

3. Measurement results

Figure 2 shows the results of the absorption coefficient measurements of the cavity. At 632.8 nm the absorption coefficient measured is 0.999885, which matches very well with the value reported by the manufacturer (0.999879). At the infrared wavelengths, the absorption coefficient varies from 0.999765 to 0.999785 between the wavelength ranges of 1280 nm – 1360 nm and 1480 nm – 1620 nm, respectively. The deviation observed for these ranges is 19×10^{-6}, which means that in this spectral range the value of the absorption coefficient is practically flat. Thus, for the whole NIR wavelength range, in principle a value of 0.999777 ± 0.000014 (k=1) can be used. Although no significant difference in the absorptance within the infrared spectral range investigated is observed, the mean value for the NIR range is about 1.1×10^{-4} lower than the value at 633 nm. This difference can be significant in the total correction factor of the CR, especially when one wish to reach uncertainties lower than 10^{-4}.

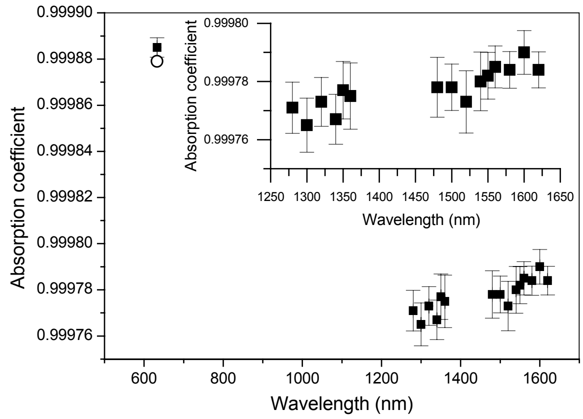

Figure 2. Absorption coefficients of the cavity measured in the visible and near infrared wavelengths. The error bars correspond to the standard uncertainty of the measurement. Open circle: manufacturer result.

4. Conclusions

The values of the absorption coefficient of a radiometer cavity in the visible and near infrared are presented. The results indicate that in the NIR, the absorption coefficient of the cavity is 1.1×10^{-4} lower than in the visible wavelength (632.8 nm).The characterization of the cavity will allow us to correct the absorption coefficient of the LaseRad cavity of the PTB cryogenic radiometer in the NIR. Thus, we expect to reach uncertainties lower than 3×10^{-4} for these wavelength ranges.

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