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Electrical substitution radiometer cavity absorptance measurement

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ABSTRACT

This paper presents the results of absorptance measurements of the cavity used in the cryogenic radiometer of the National Metrology Center of Mexico (CENAM) as absorptance device. The cavity absorptance was determined for several reference wavelengths in the visible range (VIS) using a He–Ne laser source and a tunable Ar–Kr laser at 476 nm, 488 nm, 520 nm, 568 nm and 676 nm. The absorptance value of 0.999 816 ± 1.9 × 10^{-6} ($k = 2$) at 632.8 nm obtained, matches with the reference value reported by the manufacturer of the cavity, L-1 Standards and Technology Inc., which is 0.999 823 ± 8.0 × 10^{-6} ($k = 2$). The variations found in the absorptance values goes from −4.4 × 10^{-6} to −5.1 × 10^{-7} for the wavelengths listed above.

1. Introduction

The National Metrology Center of Mexico (CENAM) has a cryogenic radiometer (CryoRad II of Cambridge Research & Instrumentation, Inc.) [1,2], used to define the radian flux unit ("The Optical Watt") at a wavelength of 632.8 nm with an uncertainty of $U_{k=2} = \pm 6.0 \times 10^{-4}$. The cryogenic radiometer is usually combined with some semiconductor trap detectors in several metrology centers of the world like CENAM, to establish and maintain the radiometric scale, due to the high level of accuracy in the optical power measurements [3]. The responsivity scale of CENAM is established by a semiconductor trap detector from 400 nm to 900 nm and it is traceable to the cryogenic radiometer at 632.8 nm [4], but it is insufficient to consolidate the internal traceability to another laboratories at CENAM (for example the photometry laboratory or the dosimetry laboratory) and also to establish the candela unit, that is a base unit of the luminous intensity in the International System of Units SI, which requires optical power measurements made in optical photometric detectors.

The optical power measurement made with the cryogenic radiometer is highly dependent of the Brewster window transmittance measurement τ and of the cavity absorptance α. In order to improve the accuracy of the power optic scale we bought a similar cavity with the manufacturer of the cryogenic radiometer to measure the absorptance value outside the instrument. The cavity under test has a length around 6 cm and an inner diameter of 7 mm. The manufacturer (L-1 Standards and Technology Inc.) reports an absorptance of 0.999 823 ± 8.0 × 10^{-6} ($k = 2$) at 632.8 nm. The intention of the experimental exercise is to confirm the flat spectral response in the lower part of the visible spectrum and define the uncertainty of these measurements.

2. Measurement method

The cavity absorptance was obtained from the diffuse reflectance ρ and the possible weak specular contributions using the relationship $\alpha = 1 - \rho$ [5]. To measure the diffuse reflectance we used an integrating sphere and a

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photodetector which transform the reflected light in a photocurrent. Fig. 1 shows the experimental arrangement.

The integrating sphere used has an internal diameter of 10.16 cm and it was coated with spectralon. The sphere has 4 ports, three of them with a diameter of 2.54 cm and the other one with a diameter of 1.27 cm usually used to mount the photodetector. To reduce the opening area of the ports and match the areas of the cavity, the detector and the white standard; three specially made Teflon adapters were designed, all with open area of 7 mm and internal diameter match with the size of the cavity, detector and white standard. The external diameter of these adapters was matched with the diameter ports. At the entrance port we used an accessory cap of the integrating sphere with an aperture of 7 mm and the unused port was covered with a Teflon capful of 2.54 cm in diameter.

The measurement method consists of a direct comparison of the diffuse reflectance reference (standard material) and the radiometer cavity, placed in the test port of the sphere alternately in a normal incidence [6]. The reflected light from the standard material is collected by the integrating sphere generating a signal in the photodetector S_s. Then the standard material is replaced for the cavity generating a signal in the photodetector S_c by the reflected light from the cavity. In this case the value of the signal obtained is considerably low because most of the light is absorbed by the cavity. Finally, a third signal S_o, is recorded when the cavity is removed from the port of the integrating sphere. The signals S_s and S_c were corrected by the S_o signal in order to correct the readings for the effects of stray light [5].

The cavity reflectance ρ_c can be obtained by the following expression [5]:

$$\rho_c = \frac{S_c - S_o}{S_s - S_o} \cdot \frac{\rho_s}{\delta} \tag{1}$$

where ρ_s is the reflectance of the standard material, and δ is the correction factor due to geometric changes in the integrating sphere during the measurement process.

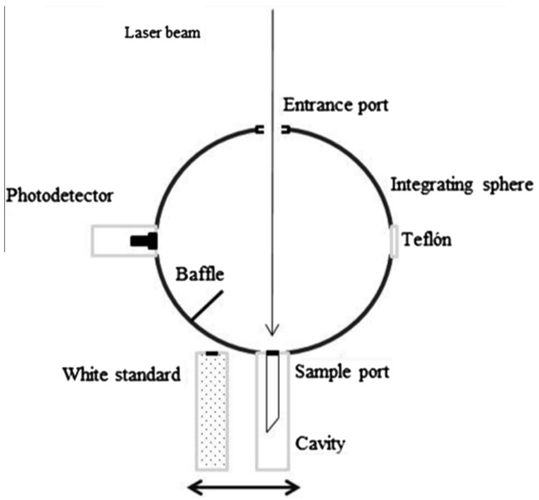

Fig. 1. Experimental arrangement with the integrating sphere for measuring the absorptance of the cavity.

It should be noted that in this work, the correction factor for geometric changes were not taken into account (by $\delta = 1$) because the used ports were adjusted to the same dimensions using Teflon coating as common material. In addition, we ensure that the white standard and the cavity were placed in the same position during the comparison process [5].

3. Measurement system

The reflectance measurement system is composed of: the X positioning sub-systems, the laser beam power stabilizer, the spatial filter beam system and the electrical measurements system. Fig. 2 shows a diagram of the measurement system [7].

As a radiation source we used an intensity stabilized He–Ne laser at 632.8 nm and also an Ar–Kr laser at 476 nm, 488 nm, 520 nm, 568 nm and 676 nm. The laser beam was controlled by a polarizing filter to reduce the power of the different wavelengths, then, the beam was stabilized in optical power by a polarizer and a commercial controller based on a liquid crystal cell. The power of the beam was monitored by a silicon photodetector which generates a feedback signal that was used into the power stabilizer system.

In order to obtain a Gaussian beam, we used a spatial filter, consisting of a 10× objective and a pin hole of 25 µm or 50 µm. The objective focuses the light beam previously stabilized to the position of the pin hole where the plane wave-front is clean from the light that accompanies the fundamental beam. The filtered light beam was defocused with a lens placed in front of the filter to obtain a reduced low divergence light beam with a diameter of 2 mm at the entrance of the cavity.

We use manual movement to position the cavity or the reference material in front of the sphere port and automatic movement for the penetration into the port in the direction of the beam propagation. The position of the beam must be carefully centered in the cavity area to avoid light loses.

4. Measuring system characterization

4.1. Position of the reference material and the cavity

Preliminary diffuse reflectance measurements showed that the photodetector signal was highly sensitive to the position of the standard material and to the cavity position inside the test port of the integrating sphere [5,6]. Because of this, it was necessary to characterize both positions with respect to the photodetector signal. The characterization was made with a laser source at 632.8 nm, shifting the standard material and the cavity alternately and recording the photodetector signal with respect to its position into the port of the integrating sphere. Fig. 3 shows the results obtained in steps of 0.5 mm.

Based on the measurements made, we determined that the best position for the standard material and the cavity was at the point at which the photodetector signal is less sensitive to displacement [5]. In the case of the standard