Construction of UV-A radiometer for irradiance measurements

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Abstract: This work presents preliminary results aiming on providing Inmetro with a radiometric transfer standard in the UV-A spectral range. A broadband UV radiometer head was constructed using an UV photodiode, a commercially available UV-A optical filter and a precision aperture. These components have been characterized in the calibration and measurement facilities available at Inmetro. The preliminary characterization of the assembled UV broadband radiometer was carried out and the results are presented and discussed in this text.

Keywords: ultraviolet, UV-A radiometer, irradiance.

1. INTRODUÇÃO

Ultraviolet (UV) light has many applications in materials processing, inspections of products and health care. These applications can require accurate monitoring of radiation levels [1-3].

Broadband UV radiation can be measured using filter radiometers whose spectral responsivities are matched to the desired spectral function. The UV-A spectral function is a rectangular shape response function which was standardized by CIE [4].

UV-A radiometers can be constructed using semiconductor photodetectors, passband filters and a limiting aperture. They are simple to construct and easy to use.

This study reports preliminary results aiming on providing Inmetro with a radiometric transfer standard in the UV-A spectral range. A broadband UV radiometer was assembled. The preliminary characterization of this broadband radiometer was carried out according to the guidelines elaborated within the Working Group of the Thematic Network for Ultraviolet Measurements [5].

2. EXPERIMENTAL PROCEDURE

Each element of the UV radiometer was characterized separately assuming that inter-reflections between filter and photodiode were negligible. The spectral transmittance of the optical filter was previously measured. The selected type of UV photodiode (GaAsP Schottky) used for the construction of the transfer standard was characterized with respect to spectral responsivity and spatial uniformity in the ultraviolet and visible spectral regions [6]. The power spectral responsivity values were measured with suitable transfer standards traceable to Inmetro´s cryogenic radiometer. The precision aperture with cylindrical edge and nominal area of 0.5 cm^2 was used in the UV broadband radiometer to define the area of the input flux for irradiance measurement. A non-contact technique was used for measuring the aperture area with an expanded uncertainty of 2.8×10^{-2} mm^2 (k = 2) [7].

The power spectral responsivity of the UV-A radiometer was then calculated from the product of the measured regular spectral transmittance of the UV-A optical filter and the power spectral responsivity of the UV photodiode.

The assembled radiometer was characterized in order to determine its performance according to reference [8]. A brief description of each characterized parameter as well as the measurement procedure is given under the following subsections.

2.1. Directional Response

The directional response describes the radiometer responsivity with respect to radiation incident at angles other than perpendicular. The ideal response would be a cosine function.

The measurement of directional response was performed under overfilled conditions using the output of a 1 kW FEL lamp as a radiation source. Lamp and radiometer were placed 1 m apart. The radiometer head was rotated about the axis passing by the center of the head aperture in the vertical direction (in the plane formed by the aperture surface). The signal was acquired every 5° step. The characteristic function f_2 describing the directional response was calculated according reference [8].

2.2. Radiometer Linearity

The linearity describes the variation of the response of the radiometer with respect to different levels of radiation.

For measuring this property, a set of neutral density (ND) filters whose nominal transmittances were 12 %, 15 %, 20 % and 40 % were used. The radiation of a 1 kW FEL lamp was directly measured by the radiometer (100 % signal) followed by attenuation of the beam by each one of the filters described above. At the end of the cycle, the stability of the lamp was checked by measuring again the non-attenuated beam. This procedure allowed testing the linearity in the range from 0.5 mW/cm² to 5.5 mW/cm².

The linearity is described by function f_3 [8], which express the maximum deviation of the linear behavior of the radiometer output when compared to the expected value. In the present case, the expected value is obtained from the known transmittances of the ND filters.

2.3. Radiometer Fatigue

The fatigue describes a reversible change of the radiometer responsivity due to submission to radiation.

The fatigue of the UV-A radiometer was measured using the UV output of a 1 kW FEL lamp. The distance of the lamp to the radiometer reference plane was one meter. The output signal (photocurrent) was measured as a function of the irradiation period keeping the lamp operating conditions constant. Furthermore, in order to follow the recommended procedure [8], the radiometer head was not exposed to radiation for at least 24 hours before starting the test. The characterization was carried out in irradiance mode and the fatigue was tested over an elapsed time of 30 minutes.

2.4. Response uniformity

The response uniformity describes the influence of non-uniform irradiance of radiometers. This parameter was evaluated by clipping the beam to a size of 2.7 mm diameter. The signal of this beam was measured in five regions in the active area: at center, and more four positions located at 90° intervals round the center of the acceptance aperture as depicted in figure 1.

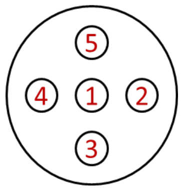

Figure 1 – Schematic representation of the clipped beam measurement in five regions over the active area of the radiometer.

2.5. Short and long wavelength responses

These parameters describe the responsivity of the radiometer outside the UV-A range.

The experiment was held using optical filters with known spectral transmittances, WG305 and GG420. The radiation from a 1 kW lamp was filtered and the short and long wavelength range responses were determined.

3. RESULTS AND DISCUSSION

The spectral responsivity of the radiometer was calculated from the spectral responsivity of the photodiode and the transmittance of the optical filter. The results are shown in figure 2.

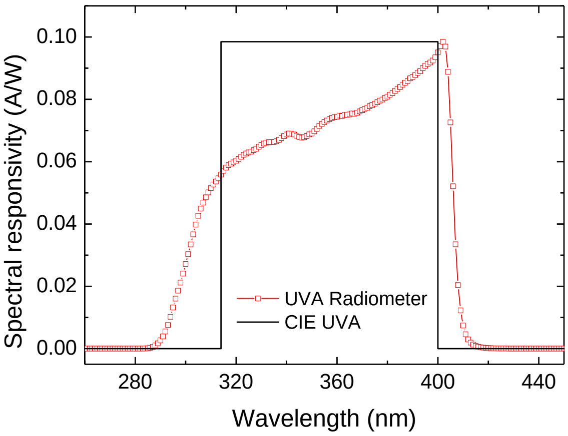

Figure 2 - Calculated spectral responsivity for the broadband UV radiometer alongside the CIE UV-A spectral function.

Figure 2 also displays the CIE UV-A spectral function. It is clear that there is a large spectral mismatch of the radiometer responsivity to the proposed spectral function. Construction of low spectral mismatch UV radiometers is challenging because of the rectangular shape of the action functions [9].

Figure 2 also indicates that there is a strong dependence of the power measured with the radiometer head on the spectral distribution of the source being measured. This poses a problem whenever the radiometer is calibrated with a kind of source and is used to measure radiation emitted by a source with distinct spectral distribution. The spectral mismatch correction factor *F* tries to account for and correct this problem. Table 1 shows this factor calculated for a set of commonly used UV lamps. The calculation was performed as described in [5] using the spectral responsivity of the radiometer and the nominal spectral distribution of the lamps [8].

Table 1 – Spectral mismatch correction factor for a set of commonly used UV lamps: Xe - xenon; LPHg – low pressure Hg; MPHg – med-pressure Hg; QTH – quartz-tungsten halogen.

Test Lamp	Calibration Lamp			
	Xe	LPHg	MPHg	QTH
Xe	1	1.7259	1.4063	1.0508
LPHg	0.5794	1	0.8149	0.6088
MPHg	0.7111	1.2272	1	0.7472
QTH	0.9517	1.6425	1.3384	1

Additionally, it is also possible to calculate the spectral mismatch factor, f'_1, which accounts for the mismatch of the radiometer head responsivity to the desired spectral function [8]. Considering the relative spectral distributions of the xenon arc lamp and the quartz-tungsten halogen lamp (QTH), the calculated f'_1 for the assembled UV-A radiometer head were 0.3621 and 0.3925. The former result is consistent with f'_1 values reported for commercial UV-A radiometers [10,11].

Table 2 summarizes the characterization results for the filter radiometer.

Table 2 – Results for the characterization of the filter radiometer.

Parameter	Symbol	Value
Directional response	f_2	8.6×10^{-1}
Linearity	f_3	5.5×10^{-2}
Fatigue (30 min)	f_5	8.0×10^{-4}
Uniformity	f_9	1.7×10^{-3}
Short wavelength response	u	5.0×10^{-2}
Long wavelength response	r	4.9×10^{-2}

The directional response of Table 2 is high compared to the other parameters. This indicates that further correction of the angular response of the radiometer is needed.

4. CONCLUSION

A special UV-A radiometer head was assembled with characterized components. Some characteristics were determined to evaluate the performance of the assembled UV-A radiometer head.

Most characteristics display values similar to commercially available UV-A radiometers. The high value of the directional response indicates need of using a cosine corrector (diffuser) to improve the radiometer directional response.

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