Spectral Irradiance Measurements Based on Detector

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Abstract. This paper presents the preliminary results of the realization of absolute spectral irradiance scale at INMETRO in the ultraviolet, visible and infrared regions using filter radiometers as secondary standards. In the construction of these instruments are used, at least, apertures, interference filters and a trap detector. In the assembly of the trap detectors it was necessary to characterize several photocells in spatial uniformity and shunt resistance. All components were calibrated and these results were analyzed to mount the filter radiometer.

1. Introduction

The realization of the spectral irradiance scale can be done using two methods, one based on the source and the other on the detector [1-3]. This second methodology was employed in this work because to be simpler and less costly and have compatible uncertainties applications for both a National Metrology Institute (NMI) and for industrial applications.

The realization of the irradiance scale based on the detector appears as a measuring chain alternative in which halogen incandescent lamps with tungsten filament is used as a source of absolute radiation. Radiometers based on reflection trap detectors in transferring the scale of absolute spectral responsivity from the cryogenic radiometer are used [4-6]. From the establishment of the spectral irradiance scale and considering all aspects of metrology, the spectral radiance scale can be developed and a new chain of traceability achieved.

2. Experimental Method

The experimental design for measuring the spectral irradiance is shown in Figure 1. A 1000 W FEL lamp was supplied with a current source of 8.2 A and it was placed at a distance of approximately 46 cm of radiometer filter (RF). A black box with an outlet aperture of about 5 cm and a shutter are used to minimize scattered light. The FEL lamp illuminates a filter radiometer which generates a photocurrent that was measured using a digital multimeter and a voltage-current converter for each filter. The idea is to construct the spectral irradiance scale using the black body model to FEL lamp
and considering the calculated current to a filter radiometer. To realize the scale it was used an interactive method in MATLAB platform as described in reference [1-3].

Figure 1 - Schematic of the experimental setup of spectral irradiance measurement.

The measured spectral irradiance is given by the following equation:

\[ E_{med \lambda} = \frac{l_{med}}{l_{calc}} E_{calc \lambda_{eff}} \]

Where: \( E_{med \lambda} \) is the measured spectral irradiance; \( l_{calc} \) is the calculated current; \( l_{med} \) is measured current and \( E_{calc \lambda_{eff}} \) is the calculated spectral irradiance.

3. Experimental Results

3.1 – Evaluation of photodiodes at spatial uniformity

The spatial uniformity measurements were taken on the laser line He-Ne of 632.8 nm. The photodiode was attached to the support that is fixed on a base and it is moved in two directions by using micrometric motorized screws, allowing the measurement of the electrical signal from the photodiode surface. The measured electrical signals along the surface are normalized with respect to the electric signal measured at the center of the photodiode. Shunt resistances of these devices were also measured. Table 1 shows each set of three photocells grouped according to closer values spatial uniformity and shunt resistance for the assembly of trap detector.

| Photodiode | Uniformity | \( R_{shunt} \) (MΩ) |
|------------|------------|---------------------|
| #1         | 0.998 – 1.002 | 258.2              |
| #15        | 0.996 – 1.002 | 267.5              |
| #23        | 0.996 – 1.000 | 262.2              |
| #7         | 0.996 – 1.000 | 284.8              |
| #8         | 0.996 – 1.002 | 287.1              |
| #16        | 0.996 – 1.002 | 289.2              |
| #11        | 0.996 – 1.000 | 285.1              |
| #14        | 0.996 – 1.000 | 281.1              |
| #24        | 0.996 – 1.000 | 280.3              |
Figure 2 shows the spatial uniformity of the photodiode #16 that is part of a set of three photodiodes mutually compatible. It is observed that the uniformity of the photodiode is similar to the other, as confirmed in Table 1. The uniformity variation among this set of photodiode (#7; #8 and #16) is less than 0.5 %. These evaluations indicate that this is a good set for the assembly of a trap detector.

![Figure 2. Spatial Uniformity photodiodes used in the assembly of the trap detectors.](image)

3.2 – Trap Detector Spectral Responsivity Measures
Measures of absolute spectral responsivity (A/W), on the laser lines of HeNe (632.8 nm) and Argon ion (457.9 nm, 488.0 nm, 514.5 nm) were made to trap detectors by comparison with the cryogenic radiometer, reference standard of optical power (W). In Table 2 are shown these measurements.

| \(\lambda\) (nm) | \(s\) (A/W) | \(u\) (A/W) |
|---------------|-------------|-------------|
| 457.9         | 0.3656      | 2.50E-04    |
| 472.7         | 0.3779      | 1.60E-04    |
| 488.0         | 0.3906      | 1.90E-04    |
| 501.7         | 0.4019      | 1.60E-04    |
| 514.5         | 0.4126      | 2.50E-04    |
| 632.8         | 0.5086      | 3.70E-04    |

Figure 3 shows the result of the comparison of the spectral responsivity to three trap detectors mounted and characterized at INMETRO. It is observed that these devices exhibit very similar behavior in terms of spectral responsivity, among the other parameters.

3.3 – Evaluation of optical filters on measures of spectral transmittance
Transmittance curves were obtained as a function of wavelength for a filter set in the range of 200 nm to 1200 nm. Figure 4 shows the results of these measurements. It was selected a set of filters on the maximum wavelengths of 380, 500, 600, 700 and 800 nm. This set was chosen because it did not show a large shift in the maximum wavelength and in the transmittance when compared with the nominal values.
3.4 – Measurement of circular apertures
Table 3 shows the measurements of the areas of the circular apertures and the respective expanded uncertainties. The uncertainty was initially available at approximately 4% and currently this parameter is of the order of 0.1%. These values are consistent with some National Metrology Institutes (NMI). NIST has values of the order of 0.004%.

| Identification code | Aperture area (mm²) | U (mm²) | u (%) |
|---------------------|--------------------|---------|-------|
| A₂                  | 7.069              | 0.009   | 0.1   |
| A₃                  | 7.074              | 0.009   | 0.1   |
| A₄                  | 7.070              | 0.009   | 0.1   |

4. Final Results and Discussion
Some photodiodes were characterized for uniformity and shunt resistance. The transmittance of interferential filters was measured. This allowed the construction of filter radiometers, Figure 5.
Some of these devices were assembled and preliminary tests were performed by determining the irradiance from the photocurrent measurement. A comparison of irradiance measurements between INMETRO ($E_{INMETRO}$) and NIST ($E_{NIST}$) shows that these preliminary results are promising, however, some adjustments in the experimental system should be carried out and the main sources of uncertainty should be evaluated. Table 4 shows the range of wavelength of the filters used in the filter assembly of the radiometer.

Table 4. Wavelength filter, versus irradiance

| $\lambda$ (nm) | $E_{INMETRO}$ (mW/m$^2$.nm) | $E_{NIST}$ (mW/m$^2$.nm) | $\frac{1-E_{INMETRO}}{E_{NIST}}$ (%) |
|---------------|-----------------------------|---------------------------|----------------------------------|
| 380           | 18.40                       | 17.50                     | - 5                              |
| 500           | 83.61                       | 81.60                     | - 2                              |
| 600           | 155.52                      | 151.00                    | - 3                              |
| 700           | 219.90                      | 207.00                    | - 6                              |
| 800           | 266.31                      | 237.70                    | - 12                             |

5. Conclusions

The first step required to achieve the scale of irradiance has been practically completed. This includes calibration of the optical and mechanical components, such as filters and apertures, and characterizing several photocells on measures of spatial uniformity and shunt resistance. Preliminary tests of spectral irradiance measurements were performed and the results are consistent with what is available in the literature. The next step to be performed is the complete characterization of filter radiometers, to consolidate the realization of the scale of spectral irradiance, comparing it with the primary standard in the field of optics, the cryogenic radiometer itself.

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