Ultraviolet Scale Realization based on a Laser-driven Light Source

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We report the successful realization of the ultraviolet spectral responsivity scale in the wavelength range between 200 nm and 400 nm at 5 nm intervals with a combined relative standard uncertainty below 0.5 % (k=1). This scale realization was based on a laser-driven light source and an absolute-cryogenic radiometer. Since both the scale realization and calibrations are performed using equivalent instruments, any uncertainty caused by differences in bandpass, out-off-band radiation, spectral purity, collimation, or extrapolation will be eliminated, leading to a more robust calibration chain.

INTRODUCTION

A few years ago, we started using a laser-driven light source in ultraviolet detector calibrations at NIST [1,2]. We realized immediately that we had enough optical power to attempt using an absolute-cryogenic radiometer (ACR) with this set up. Several problems made the primary calibration of photodiodes difficult: 1) Feeding a converging beam into the ACR and making sure the beam is not clipped was not trivial; 2) High reflectivity of photodiodes in the ultraviolet spectral region complicated the use of windows spatially close to these diodes; 3) The lack of commercially available damage resistant photodiodes with sufficient spatial uniformity. In the end we successfully calibrated three photodiodes between 200 nm and 400 nm at 5 nm intervals.

EXPERIMENT

After trying out several experimental approaches we concluded that we needed to eliminate the window in front of the photodiodes. Even with an antireflective coating, light reflected from the photodiodes and scattered by the window disturbed the measurement enough to lead to flawed results. Therefore, we settled on the system schematically shown in Fig. 1. This system used a high-quality laser-grade fused silica window in front of the ACR. The photodiodes were operated in air but placed in lens tubes in which apertures the same size and distance as in the ACR were installed, to make sure the ACR cavity and the photodiodes were seeing the same light field. The ACR and three identical lens tubes housing three photodiodes were installed on a three-axis motion stage to allow for precise positioning and spatial scanning. The light coming from the laser-driven light source was imaged onto the circular entrance aperture of a double-Czerny-Turner monochromator. An absolute angular encoder was installed on one of the grating mounts. This absolute angular encoder, in combination with a holmium oxide [3] absorption target, was used to establish the wavelength scale. The exit aperture was re-imaged using two off-axis parabolical mirrors into the ACR and the lens tubes. During the first set of measurements we used a 0.5 mm circular exit aperture, which was magnified fourfold to a 2 mm spot. Later we performed a second set of measurements with a 0.3 mm aperture to make sure the ACR cavity was underfilled.

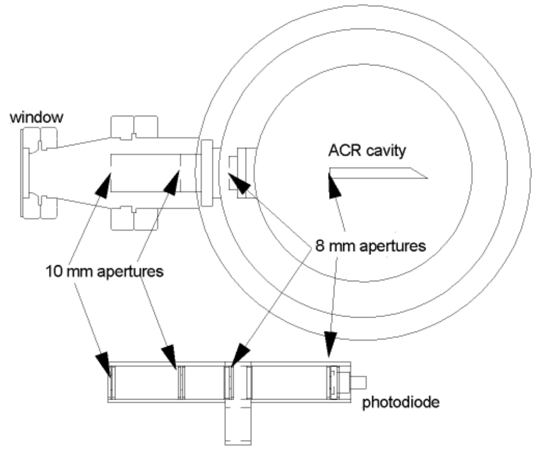

Figure 1. Schematic layout of the experimental set up.

The data acquisition was performed in the following way: The monochromator was tuned to a wavelength λ and active feedback to the absolute angular encoder was enabled to keep the wavelength constant. Then an ACR measurement of the incident optical power was performed, followed by photo current measurements for each of the three photodiodes. At each wavelength on the order of ten measurements were performed in order to identify type A random errors in the spectral responsivity measurements.

The uncertainty in transmission of the window became the largest contributor to the systematic errors in this system. After the ACR measurements were completed, the area illuminated on the window was determined. Then the window was removed, and the transmission was measured at 5 nm intervals in the wavelength range between 200 nm and 400 nm. Using the motion stage, at each wavelength a measurement with and without the window was performed. We performed this measurement six times and used the resulting mean as the window transmission.

UNCERTAINTY ANALYSIS

Careful error analysis is crucial to successful absolute radiometry. In order to quantify type A random errors, we performed about ten measurements at each wavelength and statistically analysed the result. The error analysis in summarized in table 1. The combined relative standard error can be calculated from the relative standard deviation of all systematic contributions and the random contribution divided by the square root of the number of samples.

Table 1. Uncertainty analysis for the measurement with the 500 µm exit aperture.

Type A (random error)	Relative Standard Deviation / % (K=1)
ACR Power (2nW noise)	0.02 to 2
Photodiode current	0.02 to 0.2

Type B (systematic error)	
Window transmission	0.27
Wavelength scale	0.2
Spectral bandwidth	0.1
Diode uniformity	0.1
Stray light	0.1
Positioning	0.1
Total systematic	0.39

RESULTS

To determine the true optical power, the measured optical power had to be divided by the window transmission. For each measurement the diode photo current was divided by the true optical power as measured by the ACR, leading to individual values of the responsivity. The mean of several responsivity measurements was then determined, and the standard deviation of this mean was used to estimate the type A random error.

The make sure the cavity of the ACR was underfilled, two measurements were performed: The first with a 500 µm-diameter exit aperture in the monochromator and the second with a 300 µm exit aperture. Results from both these measurements agree quite well (See table 2 for details). The differences in table 2 were calculated using equation (1). Using $\sqrt{2}$ instead of 2 in the relative difference scales the result to be equal to the relative standard deviation of the mean, while preserving the direction of the difference.

$$\Delta_R = \sqrt{2} \cdot 100 \cdot (R_2 - R_1)/(R_2 + R_1) \qquad (1)$$

Table 2. Differences in the measured spectral responsivity for detector-under-test #1 using 500 µm and 300 µm exit apertures in the monochromator.

Wavelength / nm	Difference / %
250	0.056
290	-0.031
300	0.191
350	0.188
375	-0.242

The total relative standard uncertainty, which combines the systematic and random contributions to the uncertainty is below 0.5 % (k=1) for the whole wavelength range.

CONCLUSION

We successfully performed a primary calibration on a set of three photodiodes using a laser-driven light source and an absolute-cryogenic radiometer. One of the biggest challenges we faced was the unavailability of stable and uniform diodes. The combined relative measurement uncertainty was below 0.5 % for the spectral range from 200 nm to 400 nm.

REFERENCES

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