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Construction of a Calibration System for Power Responsivity of Optical detectors Using Different Laser Sources

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ABSTRACT

Monochromators are widely used in many NMIs for realizing spectral responsivity scales of detectors because they offer an optimal trade-off between optical throughput and wavelength scale accuracy. Improving the accuracy of the measurement is one of the most challenging problems facing radiometrists today. Detectors have historically been calibrated for spectral power responsivity at the National Institute for Standards (NIS) by using a detector–monochromator system to tune the wavelength of the excitation source. Silicon detectors can be calibrated in the visible spectral region with combined standard uncertainties at the 1.2% level. We describe what we believe to be a new national laser-based facility for spectral responsivity calibrations. In laser based system, the emission from lasers is introduced into the detector surface. By measuring the output of both detectors (standard and test) and knowing the responsivity of our reference standard detectors which calibrated traceable to primary standards for spectral power responsivity at national institute of standard and technology NIST. The spectral power responsivity of the test detector can calculated.

Laser based system transfers standard detector whose responsivities are traceable to primary radiometric scales result in typical combined standard uncertainties in responsivity calibrations ranging from 0.23% to 1%. This reduces the uncertainty by two and up to 5 folds (depending on the wavelength range). The details of the facilities and comparison of their effect on responsivity measurements are discussed.

KEY WORDS: Radiometry, Silicon photodetector, Laser applications, Spectral Responsivity.

1- INTRODUCTION

The increasing variety and complexity of detector- based radiometric applications lead to the need for reduced uncertainties in detector power, irradiance and radiance measurements. Many systems had been established all over the world for spectral power responsivity [8,9]. Obviously, optical trap detectors calibrated for power responsivity using the primary standard radiometer (Cryogenic radiometer) with highly stabilized power lasers give the lowest level of uncertainty [1]. This level is decreased by transferring the trap uncertainty to a single silicon photodetector through monochromator systems. Also some can use a system consist of a set of stabilized laser sources in combination with a set of interference filters for detector responsivity calibration.[2] For laboratories lacking the financial ability to get hold of the cryogenic radiometer, a laser-based facility has been developed in conjunction with a monochromator-based one to reduce the uncertainties [3].

Recent work demonstrated a detector-monochromator-based facility typically used to calibrate test detectors for spectral power responsivity by direct substitution against a calibrated single element silicon detector in addition to a laser based system for the same calibration. The advantage of using lasers as a new calibration system at NIS calibration services is to improve the uncertainty obtained using the detector-monochromator system which is achieved by comparing the power responsivity for both detectors (standard and test) while irradiated by several discrete laser sources with different wavelengths.

In addition to addressing current industrial needs, improvements in the national spectral power, irradiance and radiance responsivity scales will directly affect the derivation of fundamental photometric and radiometric units. At NIS, for example, the photometric base unit, the candela, is currently realized and maintained on a set of standard reference photometers, and the lumen is now also realized using a detector-based system. In each case, the dominant uncertainty component in the realization of the unit is the uncertainty in the spectral irradiance responsivity of the photometers. Development of a facility capable for detector irradiance responsivity calibrations relative uncertainty level would lead to significant reductions in the uncertainties of the photometric units.

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2. Description of the facilities:

In this work, we relied on two already calibrated detectors Hamamatsu Model S2281 Silicon photodiodes namely, (8F102) as test detector and the other one (8F105), as the NIS national stranded with an active area of approximately 1cm^2. Both detectors were calibrated traceable to NIST absolute cryogenic radiometers, with uncertainty 0.38% - 1.2% (k=2) depending on the wavelength. The assumption holds to verify the measured uncertainty using two calibration systems constructed at NIS.

2-1 Detector-monochromator-based facility:

Figure 1 is a schematic diagram of the detector-monochromator based facility (DMBF). The spectral radiant power responsivity of the test detector (8F102) was determined from 400 nm to 1100 nm in 5 nm increment by comparison with the national standard detector (8F105).

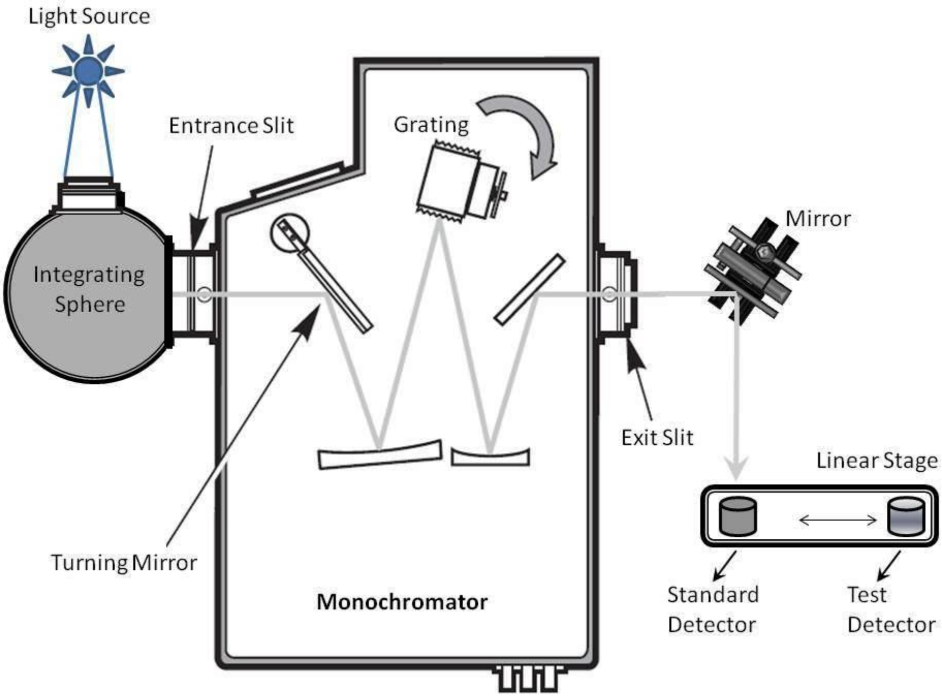

Figure 1: Schematic diagram of the detector-monochromator-based facility.

Using the DMBF the spectral comparisons between the test detector and the national standard detector were performed via a single monochromator (77700 Newport) illuminated by a Quartz Tungsten Halogen (QTH) lamp as stable visible and near infrared source.

The exit aperture of the monochromator was imaged on the test detector resulting in a beam of nearly 1.5 mm diameter at the detector surface. The beam was centered on, and under -filled the photosensitive area of the detector. A linear translation stage is used to interchange the detectors position to face the source image.

2-2 LASER source-based facility:

In this work, we constructed a simple laser-based system to determine the spectral radiant power responsivity of a test detector (8F102) in the wavelength range 594 nm to 980 nm with nine lasers (He-Ne & Diode lasers) operating at wavelengths 594, 612, 633, 650, 670, 675, 780, 850, and 980 by comparison to the NIS standard detector (8F105). Figure 2 depicts the laser-based system for detector spectral power calibration. The laser beams fall perpendicularly on the center of the detector’s sensitive area with maximum laser beam diameters of 2mm.

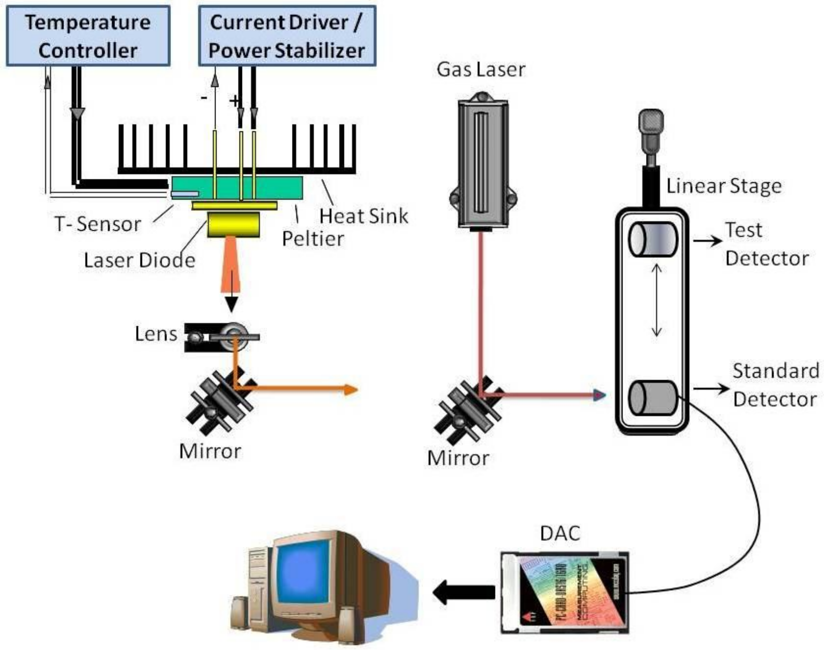

Figure 2: Schematic diagram of the laser based calibration system constructed at NIS.

3. Calibration Scheme:

The spectral responsivity of the silicon (Si) detector was measured using the two systems shown above. The measurement systems are reconstructed to calibrate detectors in the wavelength range (590 – 980 nm). The calibration procedure provides absolute spectral responsivity relative to known NIS-calibrated transfer standard (national standard).

The beam was focused to a diameter of approximately 1.5 mm at the position normal to the plane of the detector surface. The band pass of the monochromator was ≈ 4 nm.

A second system composed of set of laser sources with deferent wavelengths covering the 594- 980 nm. The laser beam was directed perpendicularly to the surface plane of the detectors. The detector was interchangeable in position using a linear translation stage. The maximum diameter of the laser beam was 2 mm. The measured responsivity of the test detector was compared with its certified responsivity in figure 3 for monochromator-based system, and figure 4 is also a comparison between the interpolated responsivity data of the laser based system and the certified data.

The test detector has been evaluated using the monochromator-based system and the laser source based system. And the responsivity calculation using both systems was compared in table 2 and figure 5.

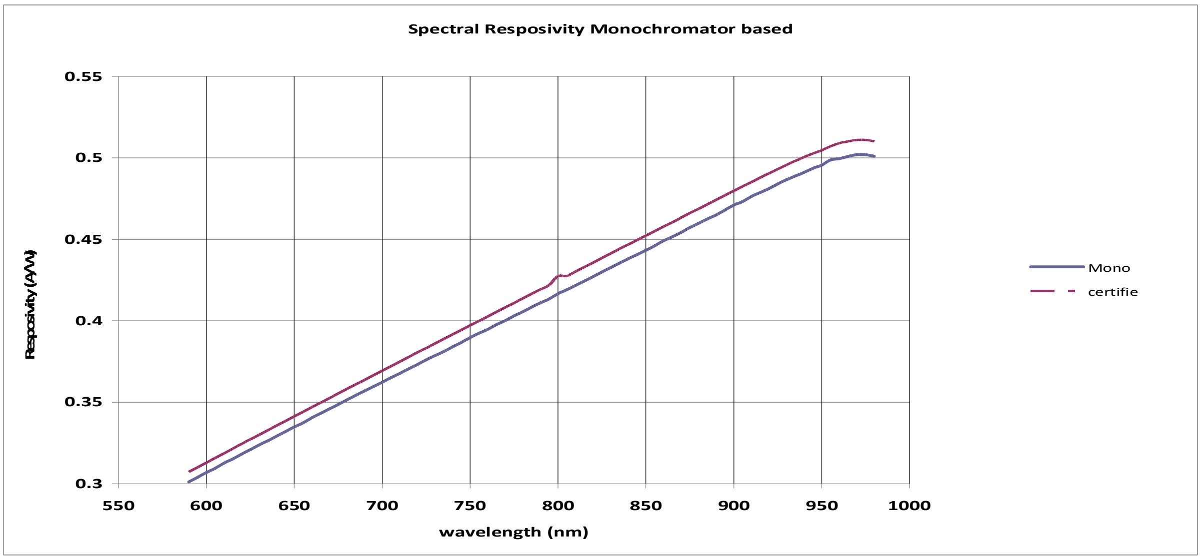

Figure 3: Comparison of spectral responsivity obtained experimentally using monochromator based facility and its certified data for the test detector.

Figure 4: Comparison of spectral responsivity obtained experimentally using LASER based facility and the its certified data for the test detector.

4- Uncertainty assessment:

The uncertainty estimates for the National Institute for Standards (NIS) spectral responsivity are assessed using NIST technical note and other publications. the uncertainty sources are separated into (1) type A whose magnitudes are obtained statistically from a series of measurements and (2) type B uncertainty whose magnitude are determined by non- tactical methods. The type A are assumed to be independent and normally distributed and the standard deviation S, for each component is

$$S = \sqrt{\frac{\sum x^2 - \frac{(\sum x)^2}{N}}{N-1}} \qquad (1)$$

Where the x values represent the individual measurements and N is the number of x values used for particular type A component.

The total uncertainty $U = \sqrt{\sum \sigma^2 + \sum \frac{S^2}{N}}$ (2)

Where $\sum \sigma^2$ the summation of type B components and $\sum \frac{S^2}{N}$ the summation of type A components.[4-7]

The uncertainty components of each system are mentioned in Table 1:

Table 1: Uncertainty component of responsivity measurements for monochromator based system and laser based system.

	Monochromator based system	Laser based system
Responsivity of reference detector	√	√
Repeatability	√	√
Amplifier	√	√
Laser stability		√
Monochromator wavelength	√	
Monochromator band pass	√	
Interpolation		√

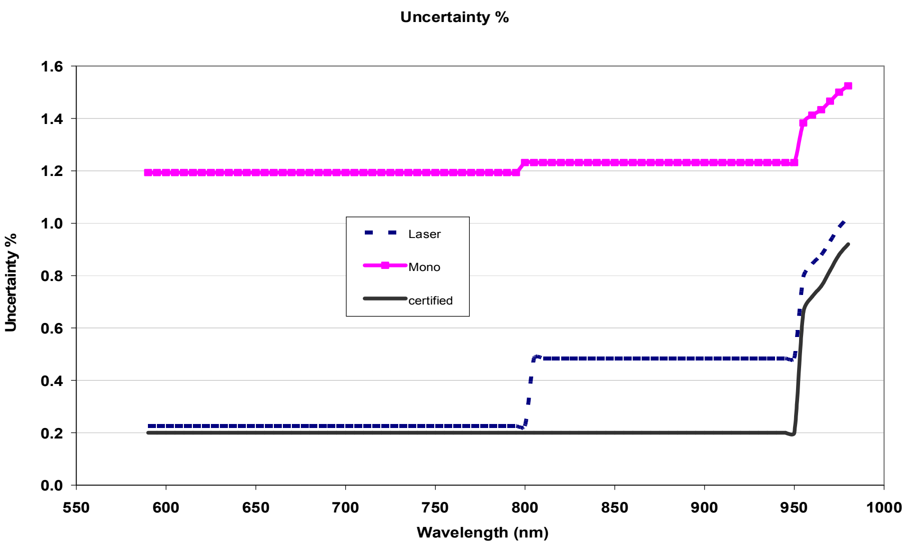

Figure 5: Uncertainty values for the test detector using monochromator based and the LASER based as in compared with the values recorded in its certification.

Table 2: Uncertainty values at different ranges for the test detector.

	Uncertainty % (k=2)		
wavelength	**Laser**	**Mono**	**certified**
594-800	0.23	1.2	0.2
805-950	0.5	1.2	0.2
950-980	≤ 1	≤ 1.5	≤ 0.7

DISCUSSION

NIS monochromator-based system has the capability to calibrate detectors in the range 250- 1100 nm. In this work all the measurements were done in the 590- 980 nm range to match the available range of discrete laser wavelengths.

Figures 3 and 4 show the comparison between the obtained responsivity by measurements using both monochromator and laser systems respectively. While figure 5 compares the uncertainty values obtained by the monochromator-based system and the discrete-laser-based one with respect to that registered in the detector certification. Although the trend of the three responsivity curves is the same for each range of the investigated wavelengths, the uncertainty values for the laser-based system is much closer to the certified values than that of the monochromator-based system.

Table 2 summarizes Figure 5 in the form of numerical values. Relying on the data obtained from both calibration systems, we can safely calibrate detectors in the wavelength range under investigation with the uncertainty quoted from the discrete-laser-based facility which reduces the uncertainty by two and up to 5 folds (depending on the wavelength range) from that obtained from the monochromator system alone.

Conclusion:

In our endeavor to reduce the uncertainty budget in calibrating silicon detectors for spectral power responsivity, we have exploited two available facilities namely, the NIS detector monochromator-based Visible to Near-Infrared spectral comparator and a less sophisticated discrete-laser-based comparator system. As expected, the laser system has a much lower uncertainty than the monochromator one. However, the comparison of the spectral responsivity data for every detector calibrated by both systems which show similar behaviors throughout the full wavelength range under investigation enabled us to reduce the relative expanded (k =2) uncertainty in measurements by an appreciable factor especially in the 594 – 950 nm range than what we would have got if we were to use the monochromator-based system alone. We have experimentally proved that this proposed method could be applied in the developing countries where the possibility of acquiring the primary standard radiometer (the Cryogenic radiometer) that usually carries a high price tag is little.

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