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SPATIAL UNIFORMITY OF THE SILICON PHOTODIODES FOR ESTABLISHMENT OF SPECTRAL RESPONSIVITY SCALE

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Abstract − The establishment of the absolute spectral responsivity scale traceable to the cryogenic radiometer depends on well-characterized optical detectors as radiometric scale transfer standards. The photodiodes used for the construction of such transfer standards need to be characterized in terms of spatial uniformity, spectral responsivity, shunt resistance and linearity. The spatial uniformity of a batch of Hamamatsu S1337-11 photodiodes was performed with a monochromatic beam in the spectral responsivity measurement facility with a *XY* translation stage. The spectral responsivity of such photodiodes had also been measured.

Keywords: spatial uniformity, spectral responsivity, silicon photodiode

1. INTRODUCTION

Photodetectors based on silicon photodiodes are widely used in optical power measurements [1,2,3]. The advantages and properties in using a silicon trap detector as absolute radiometric scale transfer standard had been reported in previous papers [4,5]. A spectral response standard detector must present some optical properties, amongst which uniformity in spectral responsivity [5]. On the process of development of the standard detector based on silicon trap detector for establishment of the spectral responsivity scale traceable to the Inmetro cryogenic radiometer, it was chosen to use *p-n* S1337-11 photodiodes manufactured by Hamamatsu. These windowless type photodiodes, which has a peak wavelength at 960 nm and active area is 10×10 mm^2 [6], showed to have a better flatness uniformity (4×10^{-4}) when compared to others silicon photodiodes [7,8]. Spatial uniformity of trap detectors built from windowless S1337-1010 photodiodes was 1 part in 10^3 at 1000 nm and 2 parts in 10^4 at 514 nm [9] and from windowless S1337-11 photodiodes was about 2×10^{-4} at 632.8 nm [10].

This paper presents a study to determine the responsivity spatial uniformity of S1337-11 photodiodes which will be selected for the construction of 3-reflection trap detectors, in order to establish the absolute spectral responsivity scale. The spectral responsivity of such photodiodes had also been measured.

2. EXPERIMENTAL SET-UP

In this study, all photodiodes were measured using the existing spectral responsivity measurement facility at Inmetro. The experimental set-up consists of a tungsten halogen lamp as radiation source. The filament of this lamp is imaged on the entrance slit of a single grating monochromator, having 250 mm focal length and 1200 grooves/mm holographic grating. Melles Griot GG395 and RG695 colored glass filters are used to suppress higher orders. Flat and spherical $f = 250$ mm mirrors are positioned at input and output slits to obtain a homogeneous and well defined beam. Generated photocurrents are amplified with calibrated Vinculum SP042 current to voltage converters and Hewlett Packard 34401A digital multimeters are used to measure the voltage. The amplifier gain for the test detector is typically 10^6. For spectral responsivity, both photodetectors, the photodiode under test and the reference detector, were mounted on the same optical rail with a computer-controlled *XY* axis translation stage and covered by a light-tight enclosure. The schematic of spectral responsivity and uniformity measurement set-up is shown in Fig. 1.

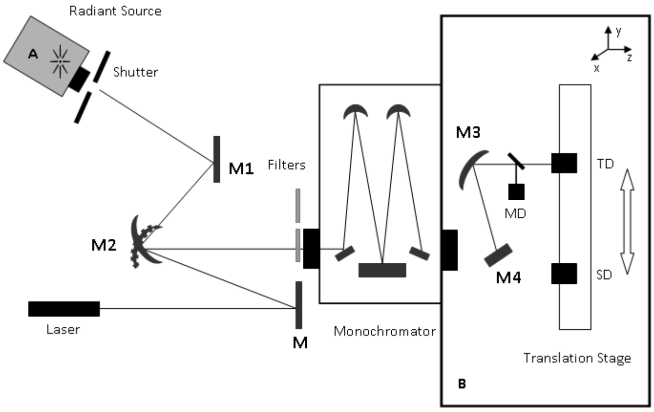

Fig. 1. Spectral responsivity and spatial uniformity measurement set-up: A – Halogen lamp; M, M1, M3 – Flat mirrors; M2, M4 – Spherical mirrors; B – Tight enclosure; F – Cut off filters; TD – Test detector; MD – Monitor detector; SD – Standard detector.

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The spectral responsivity measurement procedure, based on the substitution method, was used. The spectral response of each photodiode was obtained against a silicon detector with a known spectral responsivity as reference detector. Spectral responsivity measurements were carried out at 500 nm, 700 nm and 900 nm, and the beam diameter was about 3.0 mm at the detector surface. The typical optical power was less than 1 µW: 0.031 µW, 0.063 µW and 0.059 µW at 500 nm, 700 nm and 900 nm, respectively. Then, the monochromatic beam diameter was adjusted of about 1.0 mm at the photodiode surface and the spatial uniformity of photodiodes was investigated by scanning its active area over a 12 × 12 mm^2 area with a step width of 1.0 mm. Spatial uniformity measurements were performed only at 500 nm and 1000 nm. The typical optical power was less than 1 µW. A batch of twenty-three S1337-11 windowless photodiodes was investigated in this study, and each photodiode was placed one of each time in a black mounting with proper socket before measurement. All photodiodes were used in the photovoltaic mode, unbiased. A single S1337 photodiode detector, with known spectral responsivity, and a stationary beam splitter placed behind the monochromator are used to compensate for drifts in the radiant flux of the source. The temperature and the relative humidity during measurements didn´t vary more than 0.6°C and 2.1% (standard deviation), respectively. Measurements were carried out under dark environment conditions.

3. MEASUREMENTS RESULTS

3.1. Spatial uniformity

The spatial uniformity of each S1337-11 photodiode was investigated in the measurement system. The medium spatial nonuniformity of photodiodes was measured to be 9.4 parts in 10^4 at 500 nm and 4.6 parts in 10^4 at 1000 nm when an area corresponding to 50% of central active area was scanned and relative values to the average of the central values were used. Taking the test to monitor detector ratios, the medium spatial nonuniformity was calculated to be 1.1 parts in 10^3 at 500 nm and 1.2 parts in 10^3 at 1000 nm. No difference was verified when compared to the relative values to the center of the active area. Fig. 2a and 2b show the overall results of the nonuniformity measurements of photodiodes for relative values to the center of the active area at 500 nm and 1000 nm, respectively. Fig. 2c and 2d show the overall results of the nonuniformity measurements of photodiodes for relative values to the center of the active area, taking the test to monitor detector ratios at 500 nm and 1000 nm, respectively.

Scanned areas corresponding to 4 × 4 mm^2 and 6 × 6 mm^2 were analyzed since that the step width used was 1.0 mm. Fig. 3a and 3b show the spatial uniformity of two photodiodes analyzed.

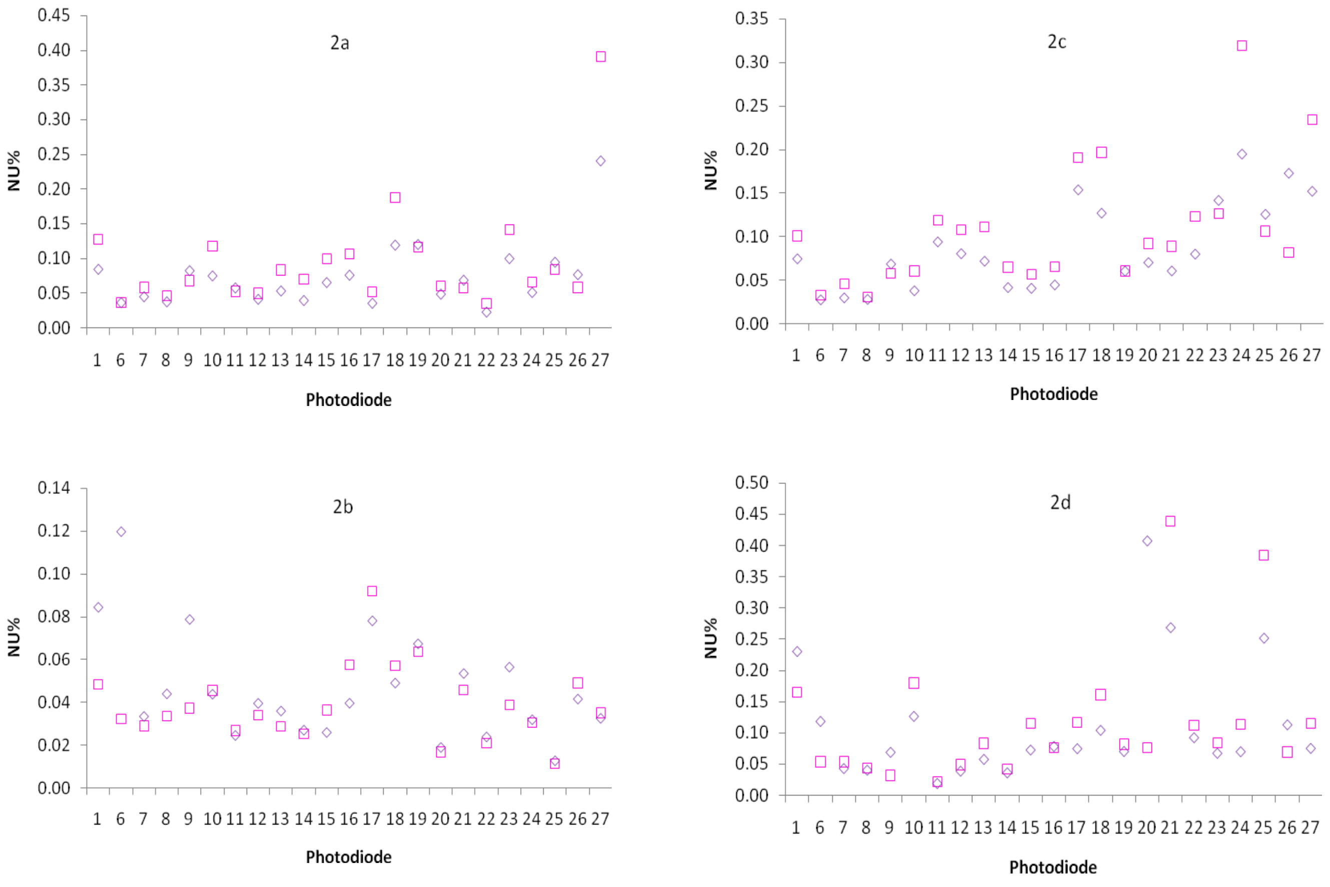

Fig. 2a and 2b. Spatial nonuniformity results at 500 nm (a) and 1000 nm (b) when relative values to the average of the central values were used with scanned areas corresponding to 4 × 4 mm^2 and 6 × 6 mm^2. Fig. 2c and 2d. Spatial nonuniformity results at 500 nm (c) and 1000 nm (d) when relative values to the center of the active area, taking the test to monitor detector.

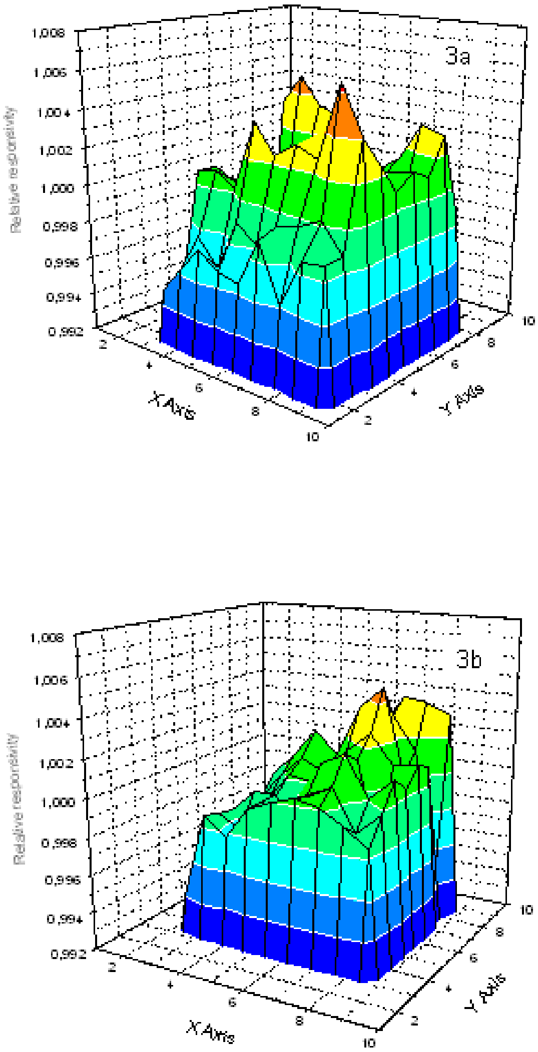

Fig. 3a and 3b. Spatial relative responsivity of S1337-11 photodiodes 6 (a) and 15 (b) at 500 nm. Responsivity values are normalized to the average of the central values.

3.2. Spectral responsivity

The spectral responsivity of single silicon photodiodes was measured in the optical set-up as described previously, with exception of the photodiode number 2 which was damaged. The relative standard deviations between individual spectral responsivity results were 8.4×10^{-3} at 500 nm, 6.4×10^{-3} at 700 nm and 6.3×10^{-3} at 900 nm. The typical expanded uncertainty was 1.5% at 500 nm, 0.59% at 700 nm and 0.35% at 900 nm. Fig. 4 show the spectral responsivity measured of each photodiode normalized by average of all photodiodes at 500 nm, 700 nm and 900 nm.

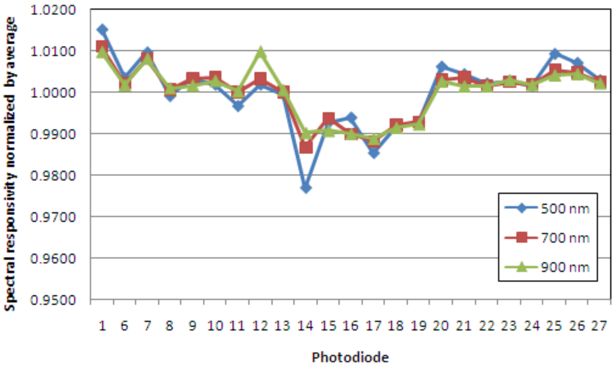

Fig. 4. Spectral responsivity measured of each photodiode normalized by average of all photodiodes at 500 nm, 700 nm and 900 nm.

4. DISCUSSION

The practice used in the selection of the photodiodes at 500 nm was the nonuniformity less than 0.5% over the active area or less than 0.25% within the 50% center of the active area. At 1000 nm, a wavelength near the bandgap (1100 nm), it was the nonuniformity less than 1.0% over the active area or less than 0.5% within the 50% center of the active area [11]. The spatial nonuniformity of photodiode 27 was measured to be 3.9 parts in 10^3 at 500 nm when an area corresponding to 50% of central active area was scanned and relative values to the average of the central values were used. Taking the test to monitor detector ratios, the maximum spatial nonuniformity of photodiode 24 was calculated to be 3.2 parts in 10^3 at 500 nm. Following the presented criterions above, these two photodiodes were considered not suitable as a transfer standard.

5. CONCLUSIONS

Measurements were realized in order to select the photodiodes with the best spatial uniformity which will be used in the construction of trap detectors for the establishment the absolute spectral responsivity scale. From the batch of the twenty-two S1337-11 windowless photodiodes that were effectively investigated in this study, only some of them not confirmed the previously achieved results. Future improvement in the measurement system with the use of a new motorized translation stage will allow the reduction of the step width of measurement, increasing the number of analyzed points, and decreasing the time of measurement. This improvement will concern in the measurement results of the spatial uniformity, contributing for the reduction of the overall spectral responsivity measurement uncertainty.

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