The effects of UV radiation on silicon detectors

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Abstract

Relative spectral responsivity measurements of detectors can be made comparing detectors against reference detectors. The radiation source used was a high-pressure mercury arc lamp, whose emission lines were selected by a simple grating monochromator from 248 nm to 450 nm. Spatial uniformity at 365 nm across the test photodiode photosensitive area was also measured. Curious behavior of silicon photodiodes occurs after UV radiation exposure. Sensitive changes and aging process occurs during calibration procedures routine. Some tests on these effects were carried out. The results, laboratory facilities, calibration method are discussed to evaluated uncertainty.

1. Introduction

The knowledge of the spectral responsivity function of detectors is determined by means of absolute or relative methods [1]. The absolute calibration is realised, usually, at one wavelength, using a cryogenic radiometer for the determination of the radiant power value with a relative uncertainty at the level of 10^{-4} [2,3]. The relative spectral responsivity of detector is defined as the ratio of the spectral responsivity $S(\lambda)$ of the detector for arbitrary wavelength λ related to the spectral responsivity $S(\lambda_0)$ of the detector at a given wavelength λ_0. In this work direct comparison method is used.

The INMETRO Radiometry Laboratory (LARAD) started in 1999 the implementation of relative spectral responsivity scale in visible and NIR spectral range by comparing silicon detectors against a reference TRAP detector having PTB traceability [4]. The extension of this scale for UV spectral range will provide traceability for industries, universities and research centres in Brazil.

2. Experimental set-up

The experimental arrangement used at LARAD is shown in Figure 1 for measurement of relative spectral responsivity and responsivity uniformity of silicon photodiode.

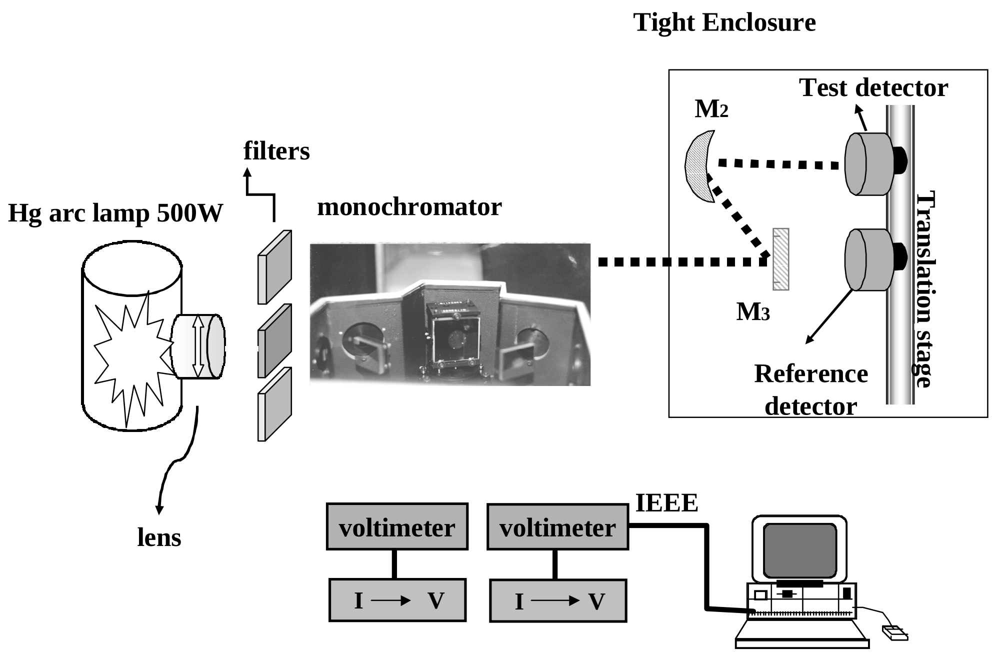

Figure 1: Experimental arrangement.

A high-pressure 500 W mercury arc lamp was used as a source light for UV measurements. The experimental set-up can employ also a quartz halogen lamp in the same facility arrangement for measurements from 400nm to 600nm. A Jobin & Yvon monochromator_ 250 mm focal length and 1200 grooves/mm holographic grating_ together with an set of mirrors and optics was employed. The monochromator was calibrated using spectral lamps. For wavelengths shorter than 450 nm, the light emerging from the lamp was imaged on the first focusing mirror of the monochromator, instead of the input slit. This provides a great uniform field on the grating [5]. The flat and spherical (f=250 nm) mirrors are positioned at slits to obtain a homogeneous and well-defined beam. The monochromator slits were 1 mm. Alignment was made with a He-Ne laser, while temperature and relative humidity were controlled in (20±1) ^{o}C and (55±5) % values, respectively.

The detector to be calibrated was silicon photodiode (Si-1143) manufactured by Newport, and as standard was used a RSP-595 silicon photodiode Laser Precision Inc. characterised by BNM/INM (France). The Si-1143 and RSP-595 detectors are mounted on the same measurement optical anodised aluminium rail with precision movement and covered by a light-tight enclosure. Both reference and test detectors were placed at the same prefixed position, alternatively, at each measured wavelength. The short-circuit photocurrent from the test photodiode and standard photodiode was measured using two converters:_ a Newport OPM 1840 C and a TRAMP- Graseby Optronics respectively. The voltmeters Hewlett Packard model 34401A are interfaced to a PC.

Effects of the UV radiation for spectral responsivity was also checked using a pyroelectric radiometer RS 5900 Laser Precision.

3. Experimental results

The relative spectral responsivity measurement of the silicon detector (Si-1143) was taken using a comparative method. This technique was based on the reading of the voltage intensity given by the converter corresponding to each wavelengths following the protocol for calibration in UV[6]. The emission line 313.85 nm was used as calibration point in UV. Calibrations at 435.8 nm were covered by visible measurements, near UV[4].

Relative spectral responsivity values of test detector were calculated according to :

$$S_t(\lambda) = \frac{I_t(\lambda)}{I_{ref}(\lambda)} S_{ref}(\lambda) \qquad [\mathrm{A/W}]$$

Being $S_t(\lambda)$ the relative spectral responsivity of test detector, $S_{ref}(\lambda)$ the spectral responsivity of the RSP-595 detector calibrated against the standard detector of BMN/INM, $I_t(\lambda)$ and $I_{ref}(\lambda)$ are signals measured of test and reference (RSP-595) detectors, respectively.

The detectors used had the same window area 1 cm^2 and the spot size were 0.5 cm^2 approximately. Transference of relative spectral responsivity scale between the test photodiode and standard photodiode were presented in Figure 2. Each point indicated in the graph curve corresponding to Hg line wavelength is the result of average processing. Insert picture in Figure 2 shows the manufacturer measurements included and also the corresponding RSP 595 BNM responsivity values for comparison.

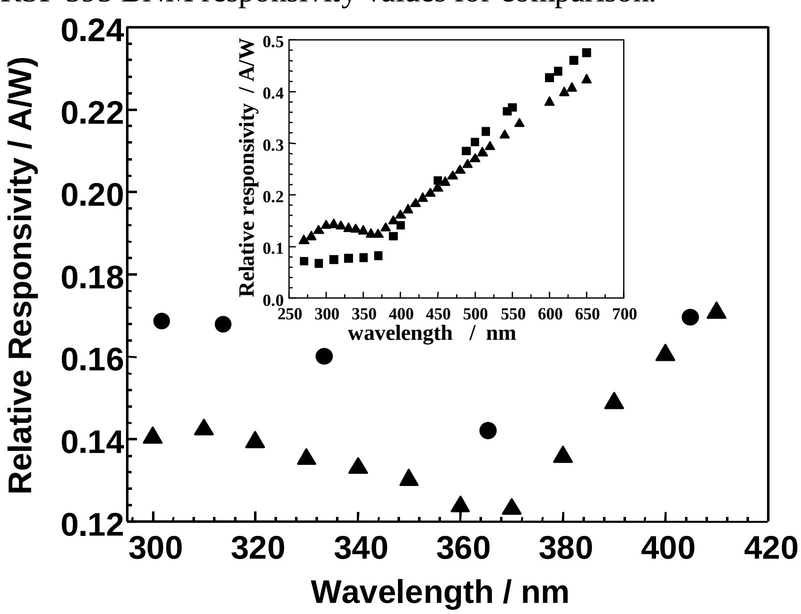

Figure 2: Relative Spectral Responsivity in the UV of tested Silicon Photodiode 1143 as measured by LARAD (circles) and according Manufacture (triangles). Insert: Comparison of RSP 595 calibration of BNM (squares) and 1143 test dectetor (triangles) given by Manufacture.

Looking at the graph (Figure 2) we can see the general shape of the spectral responsivity of the test detector measured in both places is agreement. But absolute values show a discrepancy. It seems interesting to observe that as the wavelength increases the drifts is lower.

To find explanation to the drifts in UV, the relative responsivity of the RSP 595 photodiode were obtained using other type of detector like TRAP (PTB certified) as standard. These results are presented in Figure 3.

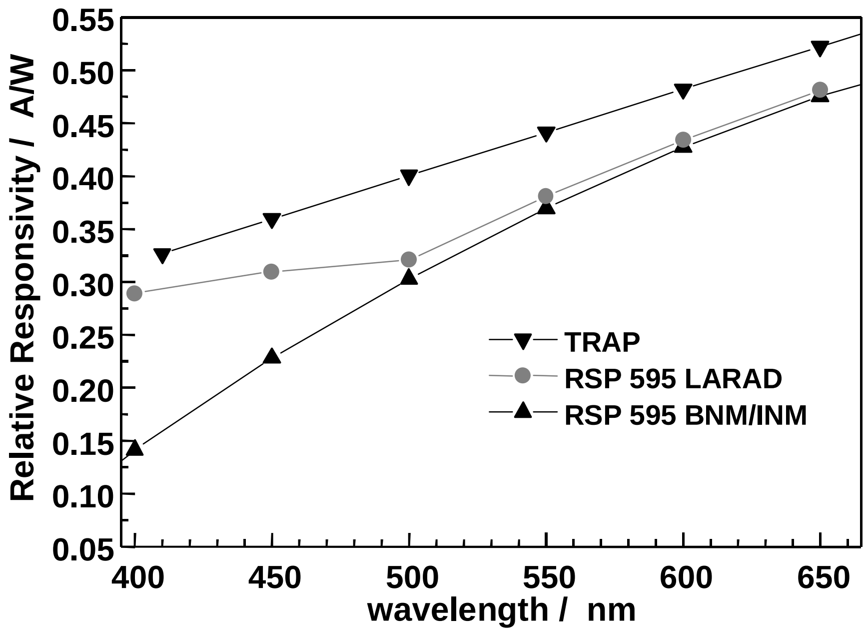

Figure 3: Calibrations comparisons. *Triangles down*: TRAP detector curve given by PTB. *Circles*: Relative responsivity curve of the RSP 595 using TRAP as standard obtained by LARAD. *Triangles up*: RSP 595 calibrated by BNM-INM. A cut-off filter was used given 100% transmittance above 500nm.

Note that the response of the photodiode RSP-595 according to BNM_INM certificate is also presented in this figure. The spacial uniformity of the responsivity across the Si-1143 detector photosensitive area was measured at 365.0 nm using an XY arrangement. The active area of the test photodiode is ≅ 1 cm^2. The uniformity measurement consists of setting the monochromator to the desired wavelength and scan the Si-1143 detector surface in 1 mm increments using a 1.0 mm using a 1.0 mm diameter beam.

Figure 4 is a plot of the spatial uniformity of response of the Si-1143 photodiode. Note that the scale is enlarged to show only the top 2 % of the available responsivity, i.e. it shows values above 98 %.

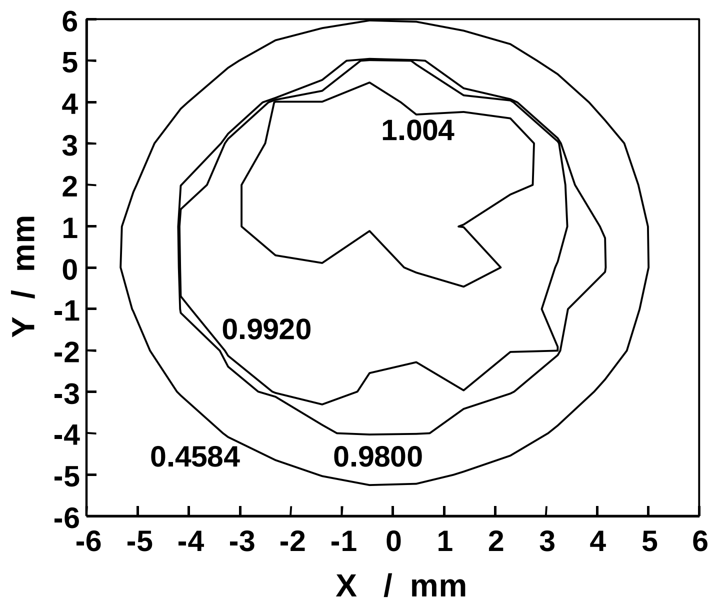

Figure 4: Verification of the spatial uniformity of response of the silicon detector model 1143 at 365 nm, measured on the monochromator facility. The increments are 1 mm.

Several factors contribute to calibration uncertainties of the test detector. The Table 1 shows the contributions of the components of type A and B uncertainties. The contributions due to the uncertainties of the Newport 1143 detector spectral responsivity were analysed and resulted in an particular relative uncertainty for each spectral responsivity values for the Si-1143 detector, according to the points used in the UV calibration process.

The values of these contributions like: stability of the system, stability of the lamp, reproducibility of centre wavelength, wavelength monochromator determination, diffuse stray radiation, spectral stray radiation, electronic instabilities and experimental standard deviation (sum in quadrature)[7], are presented in the following table.

Table 1. UV standard uncertainty.

Source of uncertainty	Relative measurement uncertainty	DVM uncertainty	Graseby Optronics (Tramp)	Newport OPM – 1830-C	Lamp Stability	System Stability	Wavelength Calibration (± 1.0 nm)	Stray Light	Bandwidth - effect	Relative Combined Standard Uncertainty [%]
Type	A	B	B	B	B	B	B	B	B	
Relative uncertainty	u(Rsi)/Rsi	u(V)/V	u(Gr)/Gr	u(Np)/Np	u(Ls)/Ls	u(Ss)/Ss	u(Rλ)/Rλ	u(Sl)/Sl	u(Bw)/Bw	
Wavelength [nm]	Estimated value [%]									Root-sum-of-squares
301.82	0.57	0.0005	-	1.0	0.12	0.05	+ 0.13	2.66	0.18	2.86
313.85	0.40	0.0005	-	1.0	0.12	0.05	- 0.21	2.73	0.21	2.95
333.48	0.25	0.0005	-	1.0	0.12	0.05	+0.19	2.44	0.16	2.66
365.43	0.21	0.0005	2.0	-	0.12	0.05	+0.02	2.36	0.12	3.10
404.85	0.19	0.0005	2.0	-	0.12	0.05	- 0.04	2.63	0.19	3.31

4. Conclusion

The realisation and dissemination of ultraviolet spectral responsivity scales require a solid-state detector with a predictable, and preferably an invariant, spectral responsivity. Unfortunately, the most widely used detector for ultraviolet, silicon photodiodes, have a spectral responsivity that varies in the ultraviolet due to multiple ionization and recombination effects [8]. Exposure to ultraviolet radiation even at low power can affect their performance.

Our initial objective was improve our responsivity spectral scale to UV starting at 248 nm (one of the lamp maximum). We consider as acceptable the emission line 301.82 nm, and we used an extra point _313.85 nm to supplies our results in a more accurate way.

But we observed strange shift, in our measurements, as shorter wavelength to be exposed at UV radiation results in a stronger responsivity change. Figure 2 shows discrepancy in the responsivity values.

Some detector which are not optimise for UV show drift in this part of the spectrum and the drift can be a lost of responsivity. So, the response given by the standard detector is lower than expected leading to higher reponsivity for the test detector.

Trying to find some explanation, the first thing we did was comparing the response of the RSP 595 detector in visible range (see Figure 3). Using appropriated filters in visible we observe a good level of response of the RSP 595 in these region. The experiment shows that the values reached by responsivity in the visible remain stable, even after UV irradiation.

By the other side, for wavelengths below 400 nm, the RSP 595 curve given by BNM, is no longer smoothly. Consequently, it is difficult to interpolate the relative responsivity curve below 400 nm and find some reasonable predictions.

In conclusion, after exposure to a 248 nm radiation, we observe strongest changes near this wavelength. We try switching off the source and interrupting the experiment and after some time, the source is switch on again: the effects of UV are cumulative. Many authors report the effects of such radiation, or of long exposure to UV, attributing it to an internal quantum efficiency damage [8,9].

The contribution arising from that experimental work permitted improve our knowledge about UV applications and cares to take in account in calibrations measurements. Perhaps further investigations about UV aging of detectors and advances in the present sets of measurement apparatus will reduce the uncertainties in the results.

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