Application of a Tuneable Pulsed Laser for Spectral Responsivity Measurements of UV Radiometers Based on Wide-Bandgap Photodiodes

Saulius Nevas[1], Philipp Schneider[1], Peter Sperfeld[1], and Niklas Papathanasiou[2]

[1] *Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin, Germany,*
[2] *sglux GmbH, Berlin, Germany*
Corresponding e-mail address: saulius.nevas@ptb.de

Compact nanosecond-pulsed and slow repetition-rate lasers can be used for direct spectral calibrations of radiometers for high irradiance level applications. UV radiometers are often built around wide-bandgap photodiodes. In this contribution we demonstrate that the radiometers may show deviations from linearity throughout the dynamic range of such measurements. This complicates the application of the pulsed lasers. The metrological problem, possible solutions and application examples are discussed in this contribution.

INTRODUCTION

Ultraviolet (UV) radiometers are widely used in various industrial applications to monitor UV radiation-induced processes like UV curing of polymers in the production of plastic parts and coatings, water disinfection, etc. There are several advantages to build the radiometers for the high UV-irradiance measurements around wide-bandgap photodiodes.

Determination of spectral responsivity functions of the UV radiometers conditioned for a high-level UV radiation is often a challenging task. Classical double-monochromator-based setups may not be capable of providing spectrally narrow and high enough irradiance levels to yield measurable signals. One metrological possibility to cope with the task is application of continuous-wave (cw) or mode-locked spectrally tuneable lasers. However, such laser systems are not widely affordable for the radiometric application due to their high costs and complexity.

Compact optical parametric oscillators (OPO) generating nanosecond pulses at repetition rates of tens to hundreds of Hz are available on the market. In contrast to cw or mode-locked systems, they are affordable to a wider range of users such as calibration and testing laboratories. It has been demonstrated that the ns-OPO systems can be successfully applied for spectral measurements of radiometric detectors using synchronised measurement techniques based on an oscilloscope [1, 2, 3] or electrometers [4]. One of the highest obstacles in the measurement application of such tuneable sources is posed by the huge energies of the laser pulses, which limits the dynamic range of the measurements due to pulse peak saturation.

Additionally, nonlinearities can be caused also by other semiconductor-related effects. For instance, solid-state detectors may exhibit supra-linearities both at low and at high irradiance levels due to semiconductor defects like charge carrier traps [5].

In this contribution we will discuss nonlinearities observed for UV radiometers irradiated by a ns-pulsed OPO source. We will also demonstrate that despite their strongly nonlinear behaviour under the pulsed irradiation the spectral calibration of the radiometers is still possible under certain conditions.

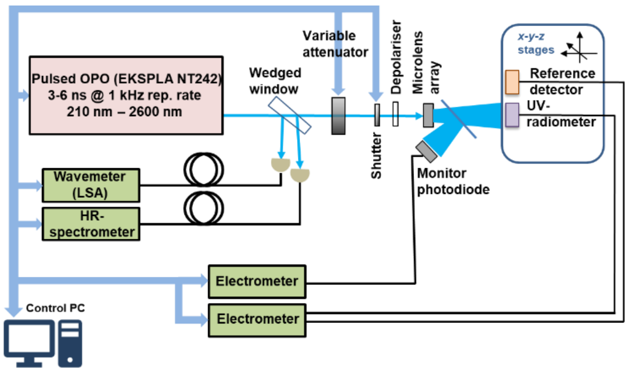

Figure 1. PTB setup based on a ns-OPO source used for the radiometric characterisations and calibrations.

PTB SETUP BASED ON A NANOSECOND-PULSED OPO

The setup based on a pulsed OPO (5 ns at 1 kHz) used at PTB for radiometric characterisations and calibrations is shown schematically in Figure 1. It has recently been taken into use as an upgrade for the PLACOS setup built around a ns-OPO at 20 Hz repetition rate [6]. While exposed to a homogenised field of the OPO radiation, the signal of the UV radiometer under test is compared to that of a calibrated reference detector based on a Hamamatsu S1227-type photodiode. An identical photodiode is also used as a linear monitor detector. For a synchronised readout of the radiometer and monitor-photodiode signals either a two-channel oscilloscope or two electrometers are used.

MEASUREMENT PROBLEM

Considering the short-pulse and low-duty cycle of the irradiating field, the first step in the measurement procedure for spectral calibration of a radiometer under test is to proof the linearity of the detector under test throughout the dynamic range of the measurements. In the setup of Figure 1, the linearity is checked by varying the irradiance level at a fixed OPO wavelength and recording signals from the detector under test and the monitor photodiode. In case of UV-radiometers based on widely used silicon photodiodes, only normal peak saturation-type nonlinearities have been observed so far, similarly to the results reported in [4].

However, for UV-radiometers including certain models of wide-bandgap photodiodes severe nonlinearities have been measured throughout the whole dynamic range. Figure 2 shows exemplary nonlinearities of two SiC photodiodes of different models. Model 2 is affected just by the peak pulse saturation while model 1 exhibits also a severe supra-linearity at lower signals. Hence, such nonlinearities may substantially limit the dynamic range of the measurements and, thus, affect the calibration significantly.

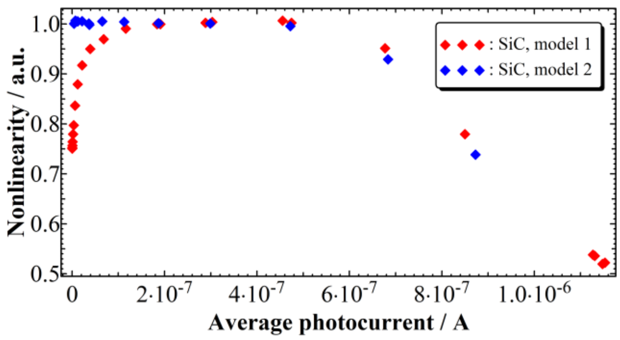

Figure 2. Deviation from linearity for two models of SiC photodiodes irradiated by the ns-pulsed OPO source at 310 nm in irradiance mode. It is shown as a function of average photodiode current.

SOLUTION AND VALIDATION

Despite the non-linearities, the UV radiometers can still be spectrally calibrated provided that the deviations from linearity under the pulsed irradiation are measured and approximated by respective correction functions. As an example, Figure 3 shows calibration results of a UV radiometer with such a nonlinearity correction applied and without it.

In the conference contribution we present results for several UV radiometers obtained using the pulsed ns-OPO setup at PTB. The results of the characterisations and responsivity calibrations are compared to those of other measurements carried out at the quasi-cw-laser setup of PTB. Moreover, the obtained spectral irradiance responsivities are also validated radiometrically by measuring several high-power UV sources.

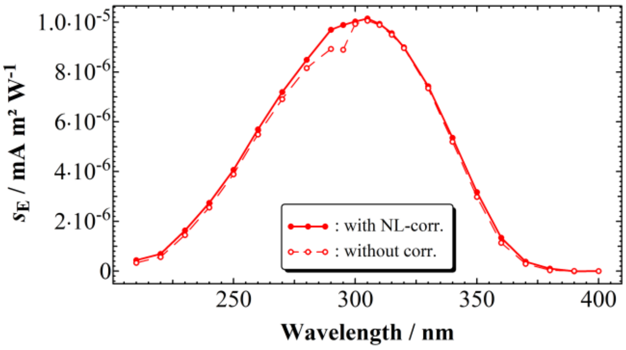

Figure 3. Spectral irradiance responsivity of a UV radiometer based on a SiC photodiode of model 1. Due to the nonlinearity, an abrupt decrease of the laser power below 300 nm causes the observed responsivity drop-off.

REFERENCES

1. M. Ojanen, P. Kärhä, S. Nevas, A. Sperling, H. Mäntynen and E. Ikonen, Double-coiled tungsten filament lamps as absolute spectral irradiance reference sources, Metrologia, 49, S53–S58, 2012.
2. S. Nevas, U. Köhler, F. Schönenborn, and G. McConville, Characterisation of Dobson spectrophotometers using a tuneable pulsed laser, in Proceedings of NEWRAD 2017, edited by Local Organizing Committee (LOC) of NEWRAD 2017, 173-175, 2017.
3. K.-S. Hong, S. Park, J. Hwang, E. Atkinson, P. Manson and D.-H. Lee, Spectral responsivity measurement of photovoltaic detectors by comparison with a pyroelectric detector on individual nano-second laser pulses, Metrologia, 54, 355–364, 2017.
4. Y. Zong, S. W. Brown, G. P. Eppeldauer, K. R Lykke and Y. Ohno, A new method for spectral irradiance and radiance responsivity calibrations using kilohertz pulsed tunable optical parametric oscillators, Metrologia, 49, S124–S129, 2012.
5. J. Metzdorf, W. Möller, T. Wittchen and D. Hünerhof, Principle and application of differential spectroradiometry, Metrologia, 28, 247–250, 1991.
6. S. Nevas, M. Lindemann, A. Sperling, A. Teuber and R. Maass, Colorimetry of LEDs with array spectroradiometers, MAPAN—J. Metrol. Soc. India, 24, 153-162, 2009.