

Measurement of the photon detection efficiency of silicon photomultipliers for the new detector cluster of the Cherenkov gamma-ray telescope TAIGA-IACT equipped with UV filters

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Abstract. This study was devoted to measurements of the UV-range photon detection efficiency (PDE) of OnSemi MicroFJ SiPM detectors use together with custom UV filters and of the transmission coefficient of these filters at 277 nm. The final goal of these measurements was to determine feasibility of the filters for the new detector cluster of the TAIGA-IACT telescope. PicoQuant PLS-270 UV source emitting pulses at 277 nm was calibrated. The obtained dependences of the registered radiation power on the distance between the emission source and the reference detector are well approximated by the inverse square function, hence no significant scattering or absorption influenced the PDE measurements. The dependences of the number of detected photons on the distance between the source and the detector were obtained. These dependencies are also well approximated by the inverse square function. The PDE of SiPM MicroFJ-60035 detector was measured at the level of $10.0 \pm 0.7\%$. The transmission coefficients of the considered set of filters at the wavelength of 277 nm were also obtained. The SL 240-300 filter has a sufficiently high transmission coefficient and it is advisable to use it as a bandpass ultraviolet filter in the new detector cluster of the TAIGA-IACT telescope; the SL 290-590 filter absorbs ultraviolet light quite well and is applicable in the visible range.

1. Introduction

The TAIGA observatory, which is a dedicated complex for studies of cosmic rays and cosmic sources of gamma-ray emission, is actively developing at present [1]. The Cherenkov gamma-ray telescope TAIGA-IACT is an important part of this observatory [2]. Its camera is based on vacuum photomultipliers [3]. However, development of silicon photomultipliers (SiPMs) makes it possible to create detection systems that would surpass the current generation of Cherenkov detectors based on vacuum photomultipliers in a number of important parameters, such as lower supply voltages, compactness, resistance to over illumination, etc. In particular, development of a SiPM-based detector cluster for the camera of the Cherenkov gamma-ray telescope TAIGA-IACT is underway at the Ioffe Institute [4]. The considered silicon photomultipliers OnSemi MicroFJ-60035 are sensitive to radiation in both the visible (300 - 600 nm) and near-ultraviolet (250 - 300 nm) ranges. The purpose of this work was determination of the UV-range photon detection efficiency of the OnSemi MicroFJ-60035 detectors combined with custom UV filters and also measurements of the transmission coefficient of these filters



at 277 nm to determine the feasibility of their application in the new detector cluster of the TAIGA-IACT telescope.

2. UV source calibration

To test the sensitive elements of the newly developed detector cluster, we have developed a dedicated test bench. The bench consists of a PicoQuant PLS-270 UV source [5] emitting 600 ps pulses at 277 nm and a rubber corrugation connecting the UV source to the detecting device and providing light isolation. At the first stage, the UV source was calibrated. For this purpose, the dependences of the radiation power on the distance between the radiation source and the reference detector were obtained. Four series of measurements were carried out both without any filters and with three types of “Photoptic” bandpass filters with transmission in the 240 – 300 nm, 280 – 390 nm, 290 – 590 nm bands. A Gentec Electro-Optics radiation power meter with a PH100-SiUV photodiode detector for laser power measurement was selected as the reference detector. The resulting dependencies are shown in figure 1. As it can be seen from figure 1, the obtained dependences of the measured power (P) on distance (L) are well approximated by the function $f(x) = a \cdot x^{-2}$

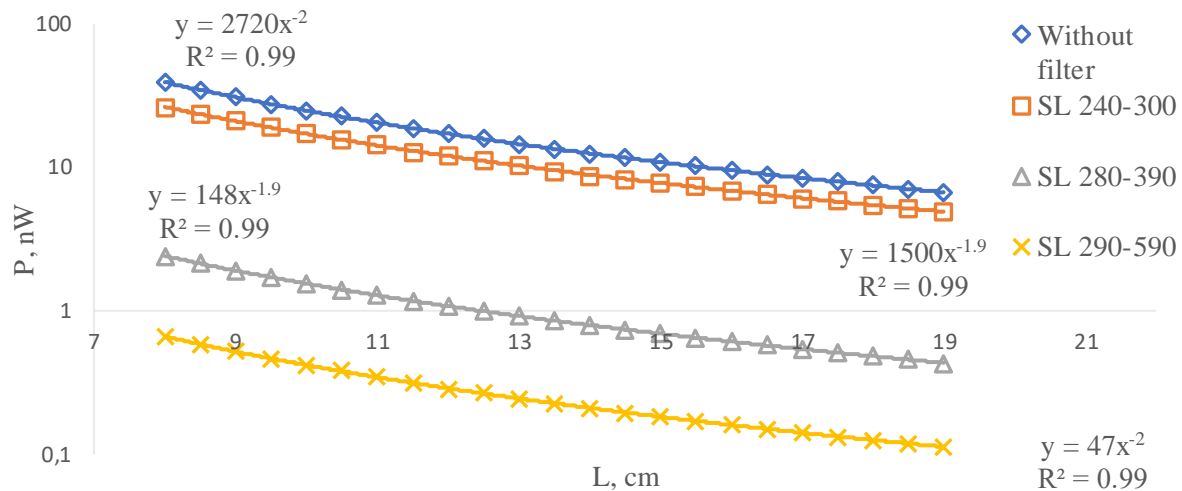


Figure 1. Dependence of the radiation power P [nW] on the distance between the radiation source and the reference detector L [cm] for measurements without a filter and with three types of bandpass filters. Solid lines represent approximating curves. The equations of the approximating functions and the R^2 confidence of the approximation are also shown. The statistical error of the measurements is insignificant and thus not displayed on the graph.

The irradiance values of the reference detector I_{ph} , which represent the number of photons per 1 m^2 of the area of the reference detector, were determined to estimate the PDEs of the SiPMs used in this study and calculated by the formula:

$$I_{ph} = \frac{P \cdot \lambda}{h \cdot c \cdot f \cdot S}$$

P - registered radiation power, W; $\lambda = 277 \text{ nm}$ the wavelength of the LED radiation, constant in all experiments; h - the Planck constant; c - the speed of light; $f = 5 \text{ MHz}$ - the frequency of the LED radiation; $S = 94.2 \text{ mm}^2$ - the effective area of the detector.

3. Measurements of SiPM characteristics

The detection unit based on the OnSemi MicroFJ-60035 was manufactured to study the characteristics of the considered SiPMs. It is a metal box with blackened inner surfaces and a rubber corrugation

connection flange [6]. The printed circuit board with MicroFJ-60035 SiPM detector is located on the case cover for an easy access to the elements. The power and signal output connectors are located on the outer side of the case cover. Each of the printed circuit boards has a preamplifier, a temperature sensor and a thermoelectric cooler to keep the temperature of the detector at $+15^{\circ}\text{C}$.

The dependences of the number of detected photons on the distance between the radiation source and the detection unit based on the SiPM OnSemi MicroFJ-60035 were obtained. The same distances between the radiation source and the detector were used as at the first stage of the experiment. After amplification by the preamplifier electronics of the units, the detector pulses were recorded by a LeCroy WaveRunner 620Zi oscilloscope with a bandwidth of 2 GHz in a DC50 mode. The measurement results are shown in figure 2. Measurements for the SL 290-590 filter were not carried out over the entire range of distances from the source to the detector, since in most cases no pulse from the detector was observed at distances above 12 cm.

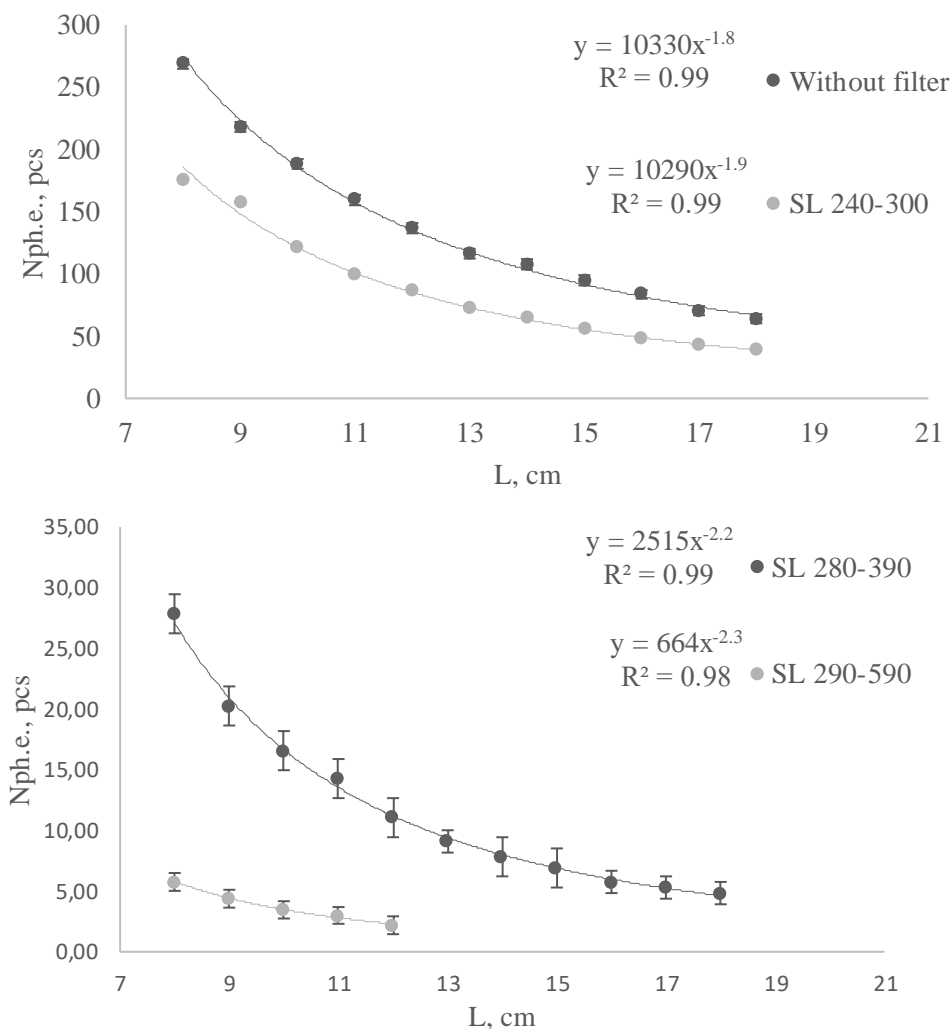


Figure 2. The dependence of the number of detected photoelectrons $N_{ph.e.}$ on the distance between the radiation source and the detector. Solid lines represent approximating curves. The equations of the approximating functions and the R^2 confidence of the approximation are also shown. The statistical measurement error displayed on the graph is equal to one standard deviation.

The irradiance of the detector $I_{ph.e.}$ was calculated from the data obtained. The calculation was made via the formula $I_{ph.e.} = N_{ph.e.}/S$, where S is the effective area of the MicroFJ-60035 SiPM detector (27.63 mm²). The PDE value of the studied SiPMs was calculated as the $I_{ph.e.}/I_{ph}$ ratio. Without a filter, the average registration efficiency (PDE) was measured as $10.0 \pm 0.7\%$, for the SL 240-300 filter – $8.9 \pm 0.2\%$, for the SL 280-390 filter – $12.8 \pm 0.6\%$, and for the SL 290-590 filter – $10.4 \pm 0.4\%$. The average PDE value between all types of measurements was about 10.5%.

4. Determination of filter transmission coefficients

The transmission coefficients T of the considered filters at 277 nm were calculated at fixed distances as the ratio of the registered radiation power with a filter applied to the power measured with the reference detector without any filter applied, or as the ratio of the detector irradiance when using filters to the irradiance of the detector without using filters when using a SiPM-based detection unit. The values of the standard deviation were also calculated under the assumption that the transmission coefficient does not depend on the distance between the radiation source and the detector. The results of the calculations are presented in table 1.

Table 1. Average values of the transmission coefficients of the considered bandpass filters at 277 nm.

Filters	Average values of the transmission coefficients T , %		Nominal T , %
	Reference detector	SiPM-based detection unit	
SL 240-300	70.2 ± 2.0	62.5 ± 4.1	66.3
SL 280-390	6.3 ± 0.1	8.2 ± 1.1	6.0
SL 290-590	1.7 ± 0.1	1.9 ± 0.2	1.7

5. Conclusions

Calibration of a PicoQuant PLS-270 UV source emitting 600 ps pulses at 277 nm was carried out. The obtained dependences of the registered radiation power on the distance between the emission source and the reference detector are well approximated by the inverse square function, hence no significant scattering or absorption influenced the PDE measurements. The dependences of the number of detected photons on the distance between the source and the SiPM-based detection unit were obtained. These dependencies are also well approximated by the inverse square function. The PDE of SiPM OnSemi MicroFJ-60035 detector was measured at the level of $10.0 \pm 0.7\%$. The transmission coefficients of the dedicated set of bandpass filters at 277 nm were obtained. The SL 240-300 filter has shown sufficiently high transmission to be employed as a pass-through ultraviolet filter for the new detector cluster of the TAIGA-IACT telescope; the SL 290-590 filter absorbs ultraviolet emission quite well and can be applicable in the visible range.

Acknowledgements

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