Measurements of the basic properties of the Multi-Pixel Photon Counter (MPPC) as a photon counting device for the future IACTs

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Abstract: A silicon photomultiplier (SiPM) is expected to serve as one of the alternatives to PMT in some fields, such as radiology, high energy physics, astroparticle physics, and so on. We studied the basic properties of some different samples of MPPCs for the application to the focal plane camera of the future IACTs. We confirmed that the properties of 3 mm×3 mm MPPCs are consistent with those expected from 1 mm×1 mm ones which we previously measured. And we verified that the differences of over voltage and temperature dependences of the gain among the different samples, such as different pixel size or different package materials, are little enough, and also that the difference of those characteristics among different channels on the monolithic array is less than 2 %.

Keywords: Imaging Atmospheric Cherenkov Telescope, Photodetector, SiPM, MPPC

1 Introduction

Ground-based very high energy (VHE) gamma-ray astronomy with Imaging Atmospheric Cherenkov Telescopes (IACTs) has grown amazingly over the last ten years. The photomultiplier tubes (PMTs) are used the most commonly as a photodetection component of the focal plane camera of current IACTs. The next generation of IACTs is planned to construct in worldwide collaborations, and SiPM (Silicon photomultiplier) is expected to be one of the optional photodetector for the imaging camera [9].

The SiPM is a novel photon detector consisting of a pixelated array of avalanche photo-diodes (APDs) operated in Geiger mode [8]. The main advantages of SiPM compared to PMT are: 1)high photon detection efficiency, 2)low operation voltage (lower than 100 V), 3)low power consumption, 4)high gain ($10^4 - 10^6$), 5)ability to detect single photon, 6)very robust, and so on. However, several disadvantages, such as too small size, the optical cross talk, the afterpulse, the high dark noise, the temperature dependences of the gain etc., are well known.

The Multi-Pixel Photon Counter (MPPC) is one kind of the SiPM manufactured by Hamamatsu Photonics K. K. in Japan. The research and development of MPPC have been made intensively by many groups ([12],[17]), and small size MPPCs have already been put to practical use in high energy physics experiments ([5],[16]). Also the responses to Cherenkov light from air showers were studied ([1],[2],[3],[11],[13]).

We have already measured and reported the basic properties of the 1 mm×1 mm MPPCs [18], such as the gain, the dark noise rate, and so on. Here in this paper, we report the results of measuring the basic characteristics of 3 mm×3 mm MPPCs, and compare them not only to 1 mm×1 mm ones, but also between different samples which are packaged by different materials. Furthermore, among the different channels on a monolithic 2×2 array type device of 3 mm square MPPCs (Fig. 1).

2 Characteristics of 3 mm×3 mm MPPCs

2.1 Measurement set-up

The MPPC is housed in a temperature-controlled dark box, where the temperature is controlled with an accuracy of $\pm 1\,^\circ$C between $-10\,^\circ$C and $25\,^\circ$C. The bias voltage, $V_{\rm bias}$, is impressed by a stabilized power supply unit in range from 66.3 V to 71.9 V. The MPPC sample is illuminated by a blue LED with a diffuser. The LED is powered by a function generator in a pulse mode of 5 kHz frequency with 8 ns width. The raw signal of MPPC is amplified about 100 times and digitized by a CAMAC ADC. The gate signal, where width is 160 ns, synchronize to the LED timing.

2.2 Gain

Geometries of measured MPPCs are presented in Table 1. Fig.2 shows an example of the charge distribution of a 2×2 monolithic array type device of 3 mm square MPPCs, for the low intensity pulsed light. Multi-photoelectron ($p.e.$) peaks are well resolved. The gain is obtained from the distance between the pedestal peak and the first peak of the

ADC spectrum.
The measured gain as a function of the over voltage ($\Delta V = V_{\rm bias} - V_{\rm break}$) is shown in Fig.3, where $V_{\rm break}$ is breakdown voltage. The data aligned to steeper slopes are for 100 μm pixel pitch sample and the data with moderate slopes are for 50 μm pixel pitch sample. It is seen in this figure that the over voltage dependence of the gain is linear. The average gain per unit voltage for 100 μm and 50 μm pitch sample are 2.2×10^6 $\rm V^{-1}$ and 5.7×10^5 $\rm V^{-1}$, respectively.
Fig.4 shows examples of measured temperature dependence of the breakdown voltage. Those slopes don't depend to the pixel capacitance which is determined by the pixel size. The average breakdown voltage per unit temperature for 3 mm×3 mm MPPC sample is 5.3×10^{-2} V $^\circ\rm C^{-1}$.
Fig.5 shows examples of measured temperature dependence of the gain. For a given bias voltage, the gain linearly decreases with the temperature. The temperature dependences of the gain are obtained -1.1×10^5 $^\circ\rm C^{-1}$ and -3.1×10^4 $^\circ\rm C^{-1}$ for 100 μm and 50 μm pitch sample, respectively. These results are consistent with those of 1 mm×1 mm MPPCs. Furthermore, there is little difference between the package materials.

Figure 1: A 2 × 2 monolithic array of 3 mm square MPPCs (Type=S10985-050C(X), ID=5).

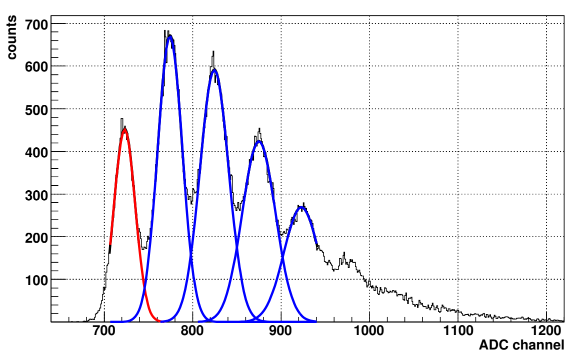

Figure 2: The ADC spectrum of ID=5 ch.1, where $V_{\rm bias}$ = 68.5 V and T=25 °C. The ADC spectrum is fitted by five Gaussian functions to find the positions of peaks.

2.3 Dark noise rate

Dark noise rate is measured by counting the number of events above voltage level of 0.5 $p.e.$ and 1.5 $p.e.$ threshold. The results are shown in Fig.6 as a function of over voltage, for each given temperature. It is clearly seen from this figure that the dark noise rate increases rapidly both with temperature and with over voltage. Dark noise rate 3 mm×3 mm MPPCs are typically a few MHz at room temperature. The results also show that the differences of the package materials little affect the noise rate. This rate are several ten times higher than those of 1 mm×1 mm MPPCs, and slightly exceeds the expected values of dark rate evaluated from the difference of the photosensitive area.

3 Characteristics of a 2×2 monolithic array of 3 mm square MPPCs

We tested the basic characteristic of a 2 × 2 monolithic array device which consists of four 3 mm square MPPCs. The over voltage and the temperature dependences of the gain are measured.
The average gain per unit over voltage is 6.0×10^5 $\rm V^{-1}$ which is almost constant with the temperature (Fig.3), and there is only less than 2 % difference among the channels. The temperature coefficient of the gain for a bias voltage of 68.0 V is obtained to be -3.2×10^4 $^\circ\rm C^{-1}$ which corresponds to about 3 % of the gain variation per unit temperature for 10^6 gain operation (Fig.5).

4 Summary

We have measured the basic properties of 3 mm×3 mm MPPCs and a 2 × 2 monolithic array of 3 mm square MPPCs. The results show MPPC is a promising photodetector to replace PMT for future application to some experiments. However, it is rather clear that the present properties must be improved particularly for the ground-based gamma-ray telescopes.

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Table 1: Specifications of 3 mm×3 mm MPPCs and a 2 × 2 monolithic array of 3 mm square MPPCs

Sample ID	Type	Photosensitive area	Number of pixels	Pixel pitch [μm]	Package
455	S10362-33-050C	3 mm×3 mm	3600	50	Ceramic
464	S10362-33-100C	3 mm×3 mm	900	100	Ceramic
75	S10931-100P(X)	3 mm×3 mm	900	100	Plastic
5	S10985-050C(X)	2×2 monolithic array			Ceramic
ch.1		3 mm×3 mm	3600	50	
ch.2		3 mm×3 mm	3600	50	
ch.3		3 mm×3 mm	3600	50	
ch.4		3 mm×3 mm	3600	50	

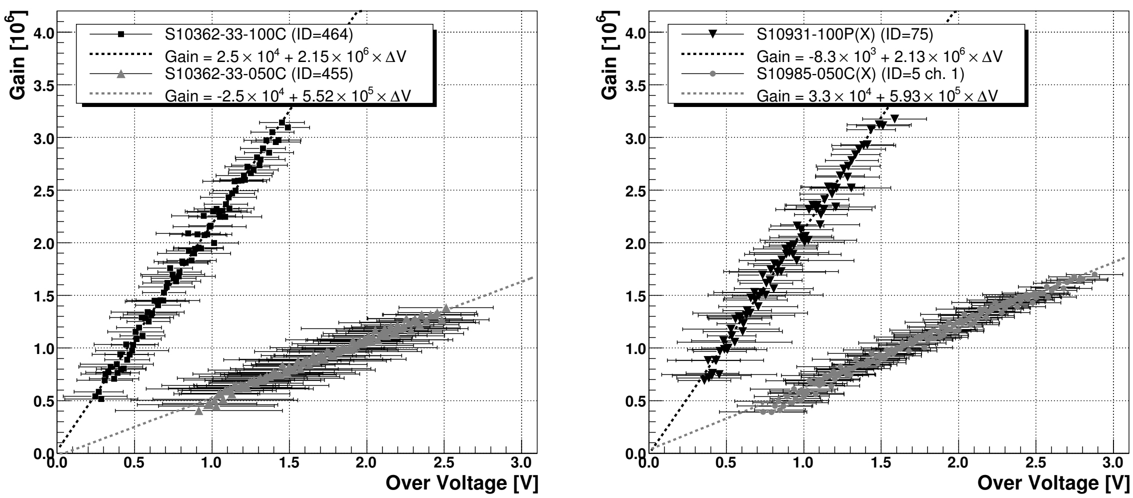

Figure 3: Over voltage characteristics of the gain of 3 mm×3 mm size MPPCs. The left panel is the characteristics of ID=464 (squares) and ID=455 (triangles). The right panel is those of ID=75 (reverse triangles) and ID=5 ch.1 (circles).

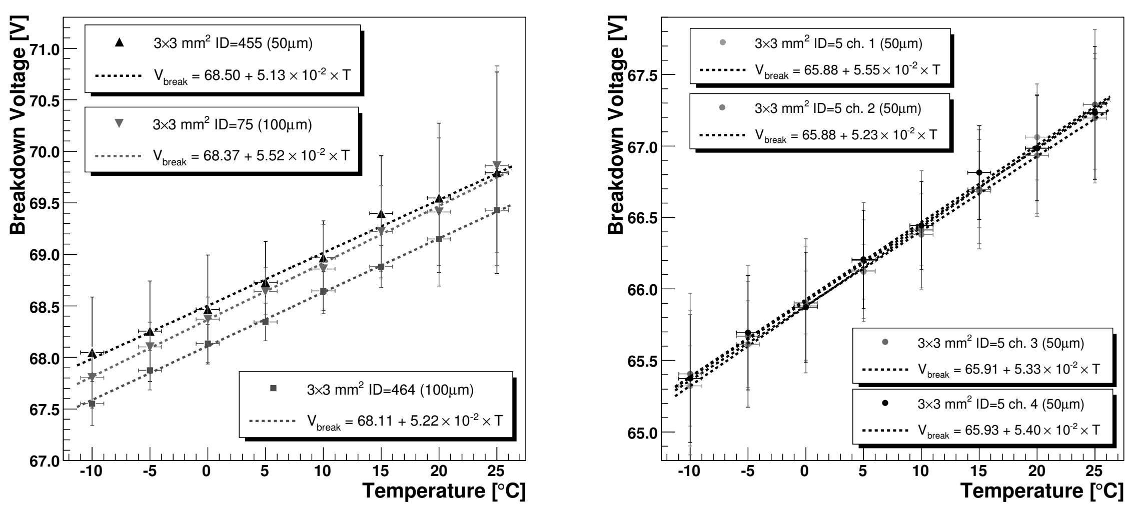

Figure 4: Temperature characteristics of breakdown voltage of 3 mm×3 mm size MPPCs. The left panel is the characteristics of ID=464 (squares), ID=455 (triangles) and ID=75 (reverse triangles). The right panel is those of ch.1 from ch.4 on ID=5 (circles).

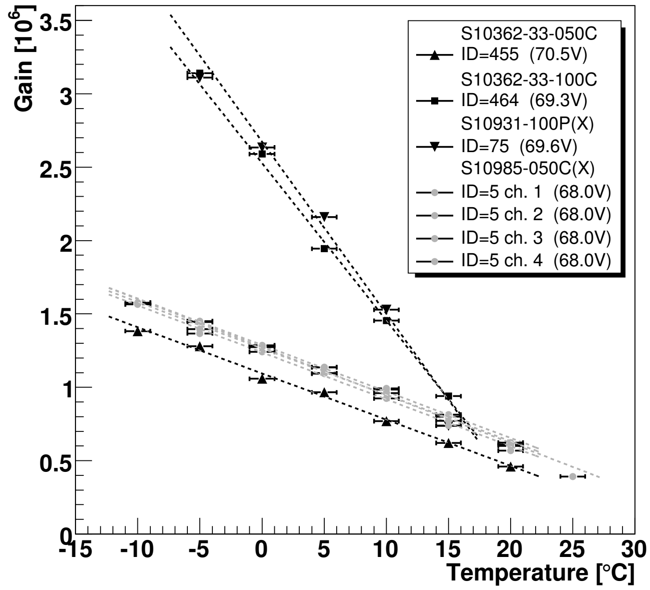

Figure 5: Temperature characteristics of the gain of 3 mm×3 mm size MPPCs, where ID=464 (squares), ID=455 (triangles), ID=75 (reverse triangles) and ID=5 (circles). The data for the case of 100 μm pitch samples to which 69.3 V and 69.6 V of bias voltages are applied, respectively, and the data for 50 μm pitch samples applied 68.0 V and 70.5 V, respectively.

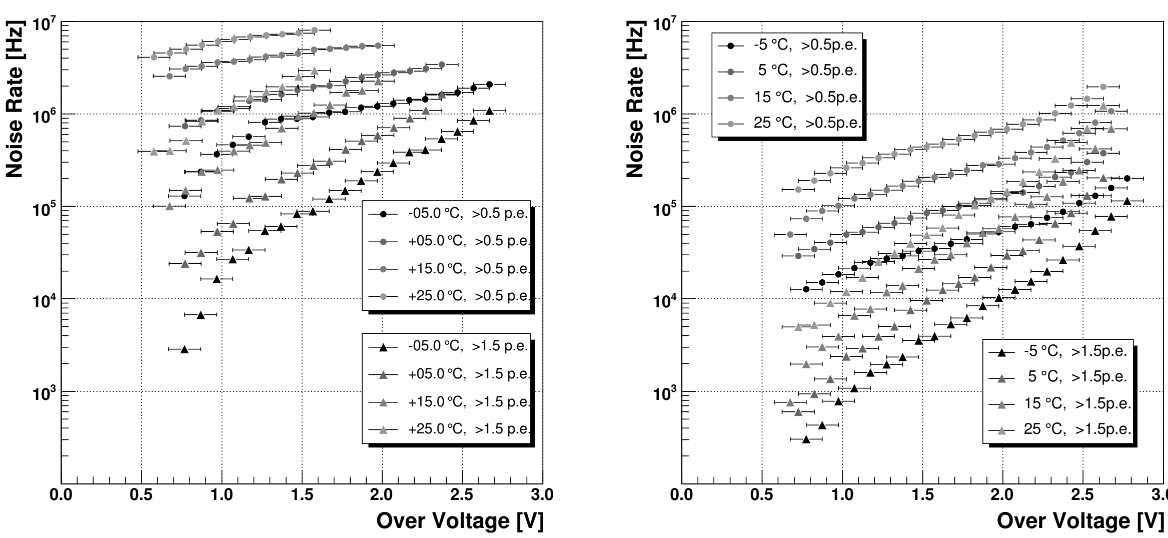

Figure 6: Over voltage characteristics of dark noise rate of 3 mm×3 mm size MPPC (ID=455) and 1 mm×1 mm size MPPC (Type=S10362-11-050C and ID=602). The specifications of ID=602 is 50 μm pitch and the ceramic package samples. The left panel is the dark noise rate of ID=455 and the right panel is those of ID=602. Here, dark noise rate are measured by counting the number of events above voltage level of 0.5 *p.e.* (circles) and 1.5 *p.e.* (triangles) threshold. The temperature was controlled. (T=-5 °C, 5 °C, 15 °C, and 25 °C).