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Performance Test of New-type MPPC

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Multi-Pixel Photon Counter (MPPC) is a silicon photomultiplier (SiPM) device made by Hamamatsu Photonics. In high energy physics experiments, MPPC with low crosstalk has been desired for a good photon counting resolution. Recently, Hamamatsu has developed a new type of the MPPC which has a lower crosstalk probability and therefore a better photon counting resolution with pixel size as small as 10 μm. This was achieved by Hamamatsu's new trench isolation technology. In this paper, we show results of the measurement of this new MPPC's performance.

KEYWORDS: MPPC, crosstalk, dark noise, gain

1. Introduction

Silicon photomultiplier (SiPM) consists of a number of arrayed avalanche photodiode (APD) pixels which are operated at the Geiger mode. The output signal size is proportional to the number of pixels which detect photons and therefore it has a good capability of photon counting. Multi-Pixel Photon Counter (MPPC) is a SiPM device developed by Hamamatsu Photonics and used in various high energy physics experiments [1, 2].

To obtain a higher dynamic range, the number of APD pixels needs to be larger and hence smaller pixel size and higher density is required. However, with smaller pixels, SiPM is more prone to the noise of photons from neighboring active pixels, and so-called "crosstalk" increases. Thus, it has been a long-term challenge to develop low-crosstalk MPPC with small pixels.

Recently, Hamamatsu Photonics has developed "the 4th generation MPPC (S14160 series)," which has a lower crosstalk probability than the present one, even with small pixels such as 15 μm. This was achieved by Hamamatsu's new trench isolation technology. This new technology enables the isolation even with 10 μm pixels and leads to a low crosstalk probability while keeping a high dynamic range.

It should be also noted that this MPPC's breakdown voltage is as low as 38 V and has large gain under a low voltage operation.

In this paper, we will show the first results of voltage or temperature dependences of the gain, dark count rate, and crosstalk and afterpulse probability of this new MPPC.

2. Measurement

First, the evaluated sample type is S14160 with sensitive area of 3×3 mm^2 and 15 μm pixel size. A testing board includes two low-pass power line filters composing 100 kΩ resistors and 0.22 μF capacitors. The MPPC output is terminated with 50 Ω.

Second, The board was enclosed in an aluminum noise-shielding box (size: $3.5 \times 8.0 \times 12.5$ cm^3) and connected to a fast preamplifier with a gain of 80. In order to reduce further the noise, the connection between the aluminum box and the pre-amplifier was made to be as short as possible.

Third, the box and the amplifier were put in a temperature constant bath and the dark current data for different voltages and temperatures were taken with a 12-bit charge-sensitive ADC and the periodic trigger. The applied bias voltages and temperatures are listed in Table I. In order to estimate the pedestal peak, the data without applying voltage for each temperature were also taken. The 200 ns gate signal was made by a 100 Hz clock generator.

Table I. The applied voltages to the MPPC and temperatures are listed. The voltages were controlled by the power supply and the temperatures by the constant temperature bath.

Voltage [V]	Temperature [°C]
0.0	15.0, 20.0, 25.0, 30.0
46.5	25.0
47.0	15.0, 20.0, 25.0, 30.0
47.5	25.0

3. Result and Discussion

ADC spectra are shown in Fig. 1. The pedestal counts were subtracted from the raw spectrum to obtain 1 photoelectron (p.e.) peak plot. The scaling factor of the pedestal data was calculated from the area lower than the mean value of the pedestal peak where we assumed only pedestal counts contributed. By fitting a gauss function to this signal peak, the number of 1 p.e. counts was obtained as the area of fitted gaussian. The fitting area includes only the neighborhood of the peak not to take 2 p.e. contribution into account. Poisson equations allow us to calculate gain, dark rate, crosstalk and afterpulse probabilities using the ratio between pedestal and 1 p.e. counts.

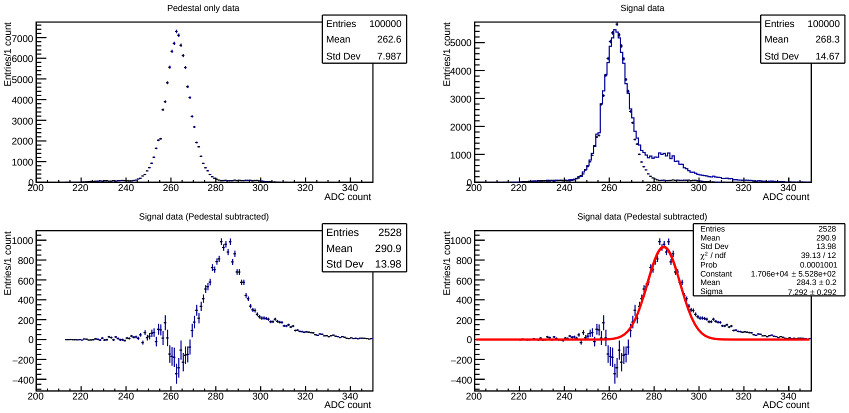

Fig. 1. The histogram of dark current data were obtained with the 12-bit ADC. The right-upper figure shows the data of 47 V, 25 °C and the left-upper one the pedestal data. The pedestal data were scaled and subtracted, and 1 p.e. signal data which is shown in the left-bottom figure were obtained. The number of 1 p.e. counts was calculated by the gaussian fitting to its peak as in the right-bottom figure.

3.1 Gain

The gain of MPPC is defined as how many electrons are obtained when one photon is detected. In this study, the gain was calculated as

$$\frac{(\mathrm{Peak_{ped.}} - \mathrm{Peak_{1\ p.e.}}) \times 1000\ [\mathrm{pC}]}{4095 \times 80 \times (1.6 \times 10^{-7}\ [\mathrm{pC}])} \tag{1}$$

where $\mathrm{Peak_{ped.}}$ and $\mathrm{Peak_{1\ p.e.}}$ are the ADC counts of the pedestal peak and the 1 p.e. peak, respectively, 1000 pC is the upper limit of charge of the ADC, 4095 equals to 12-bit, 80 is the amplification factor of the pre-amplifier, and 1.6×10^{-7} pC is the elementary charge.

The dependencies on bias voltage and temperature are shown in Fig. 2. The gain was proportional to the voltage and got smaller under higher temperature and the same voltage.

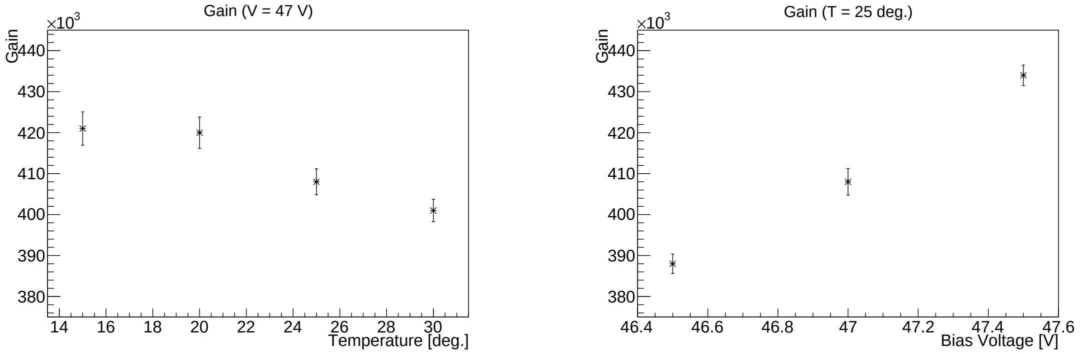

Fig. 2. The gain for each temperature (left) and voltage (right) was calculated. The error bars represent statistical errors from the fitting.

3.2 Dark count rate

In this measurement, the dark count rate was calculated assuming the Poisson distribution as

$$\frac{\sum_i i \times \mathrm{Noise}_i}{200\ [\mathrm{ns}] \times 9\ [\mathrm{mm}^2] \times 10^6} = \frac{-\ln(\mathrm{Noise}_0/10^6) \times 10^6}{200\ [\mathrm{ns}] \times 9\ [\mathrm{mm}^2] \times 10^6} = \frac{-\ln(\mathrm{Noise}_0/10^6)}{200\ [\mathrm{ns}] \times 9\ [\mathrm{mm}^2]} \tag{2}$$

where, Noise_0 and Noise_i are the number of pedestal and i photons dark noise events, 200 ns is the width of the gate signal, 9 mm^2 is the area of the MPPC, and 10^6 is the total number of events in the measurement.

The result plots are as shown in Fig. 3. The dark count rate goes up with higher temperature as such a noise is due to the thermal excitation. It shows weak variations on bias voltage with the average value of around 130 $\mathrm{kcps/mm}^2$ at the 47 °C.

3.3 Crosstalk and afterpulse probability

In this measurement, the contributions from the crosstalk and afterpulse were not distinguished. When such contributions are included, the 1 p.e. events will differ from the expected value and the crosstalk and afterpulse probability was calculated as

$$\frac{\text{expected 1 p.e. events} - \text{observed 1 p.e. events}}{\text{expected 1 p.e. events}} \tag{3}$$

where, “expected 1 p.e. events” is calculated as $-\ln(\mathrm{Noise}_0/10^6) \times \mathrm{Noise}_0$ under the Poisson distribution.

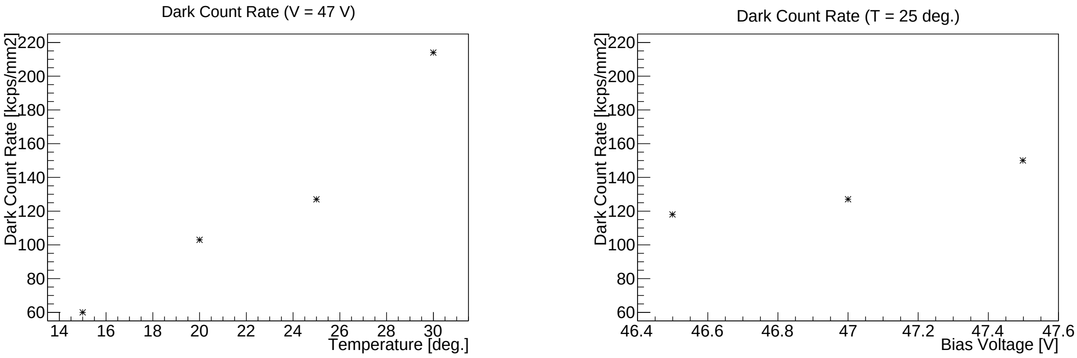

Fig. 3. The dark count rate for each temperature (left) and voltage (right) was calculated. Errors are not shown in these plots.

The result is shown in Fig. 4. The crosstalk value was decreasing as linear function at higher temperature because the overvoltage was decreasing too. The crosstalk was measured to be less than 10 % at the operational bias voltages and room temperature.

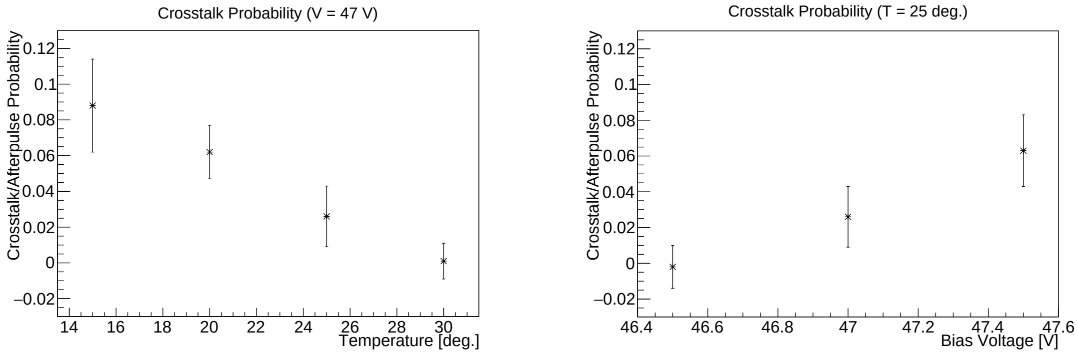

Fig. 4. The crosstalk and afterpulse probabilities were calculated assuming the Poisson distribution.The dependences on the temperature (left) and the voltage (right) are shown. Errors are from the gaussian fitting. The errors are larger than the other two parameters and the values are preliminary.

4. Conclusion

In conclusion, we have measured the parameters of Hamamatsu MPPC type S14160 of 3×3 mm^2 size with 15 μm pixel pitch. Our results have proved that Hamamatsu trench isolation technology keeps the dark rate below 200 kcps/mm^2 and suppresses the crosstalk to the level as low as 10 %. This MPPC will be useful in various high energy experiments and will improve the measurement precision because of its low noise and high dynamic range characteristics.

References

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