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Development and study of the multi pixel photon counter

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Abstract

The Multi Pixel Photon Counter is a novel semiconductor photon sensor which consists of 100–1600 micro APD pixels. Each pixel works in limited Geiger mode with an inverse bias voltage around 80 V. The MPPC has many remarkable features such as high gain, large photon detection efficiency, low cost and tolerance for magnetic field. Fundamental properties, such as the gain, dark noise rate and inter-pixel cross-talk, have been measured with three different samples which have 100, 400, and 1600 pixels. Variation of the gain over 750 samples, and uniformity of the gain and photon sensitivity within one pixel are also evaluated. As the result of the tests, it is confirmed that the MPPC has satisfactory performance for many applications, not only for high energy physics experiments but also for medical engineering systems.

PACS: 29.40.Wk; 29.40.Mc; 29.40.Vj

Keywords: MPPC; Silicon photomultiplier; Photon sensor

1. Introduction

The Multi Pixel Photon Counter (MPPC) is a novel semiconducting photon counting device manufactured by Hamamatsu Photonics K.K. [1,2]. The MPPC consists of 100–1600 micro APD (Avalanche Photo-Diode) pixels as shown in Fig. 1. Each pixel works in limited Geiger mode with an inverse bias voltage around 80 V, which is a few volts above the breakdown voltage. If a photon hits a pixel and produces a photoelectron, the photoelectron induces a Geiger avalanche. Since one pixel saturates with one avalanche, the multi-pixel structure is necessary to count the number of photons. The avalanche signals from all the pixels are summed up and read out as a signal. Fig. 2 shows spectra of the MPPC signal for a LED light pulse taken with a charge integrate ADC. There are more than 10 photoelectron peaks which are well separated, which proves excellent photon counting ability. As well as the photon counting ability, the MPPC also has many

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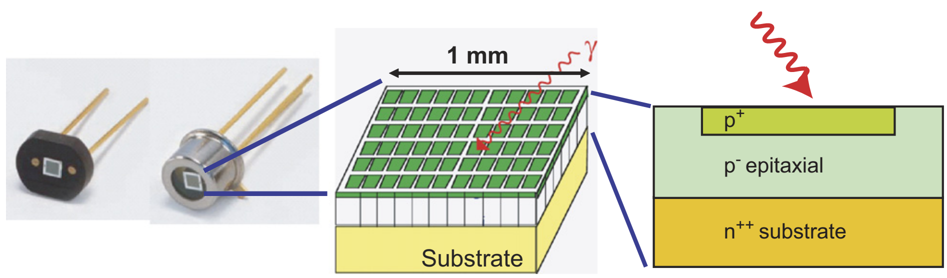

Fig. 1. Picture and schematic drawings of the MPPC.

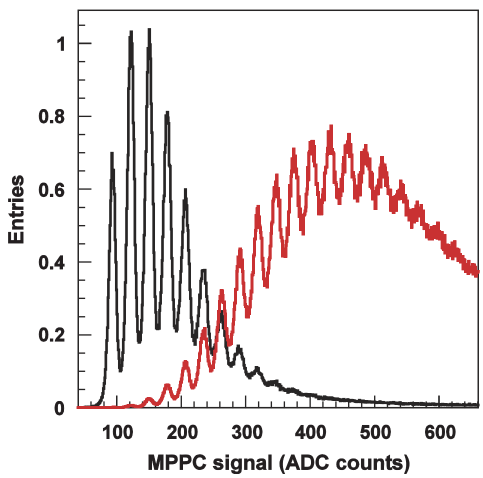

Fig. 2. Spectra of the MPPC signal taken with LED light pulses.

remarkable features, such as high gain, large photon detection efficiency, low operation voltage (~80 V), magnetic field tolerance and so on. However there are some points, such as dark noise, inter-pixel cross-talk and sensitivity to temperature change, which must be improved in future developments.

2. Fundamental performance

We have measured the properties of the MPPC under several different bias voltages and temperature points. Fig. 3 shows the gain of the three different types of MPPCs. There is a linear relation between the gain and the bias voltage, and the relation is expressed by the formula Gain $= C/e(V_{\text{bias}} - V_0)$, where C is the capacitance of 1 pixel, and V_0 is the breakdown voltage, which corresponds to a starting voltage of the Geiger-avalanche amplification. The gain is typically of the order of $10^5 - 10^6$. Since the different types of MPPC have different pixel capacitance, the MPPCs with the smaller number of pixels have higher gain. The variation of the pixel capacitance and the breakdown voltage over 750 samples of the 1600 pixel MPPCs are also measured and shown in Fig. 4. The variations of C and V_0 are 4% and 0.45 V, respectively.

The rate of dark noise is measured and shown in Fig. 5. The noise rate is typically 100–300 kHz, and it significantly increases with over-voltage ($V_{\text{bias}} - V_0$), and also strongly depends on temperature.

Fig. 6 shows the probability of inter-pixel cross-talk. The inter-pixel cross-talk is caused by a photon created in an avalanche going into N adjacent pixels and inducing another avalanche. To measure the probability of the cross-talk, the dark noise rates corresponding to 1 and 2 pixel fired signals are used. Since the dark noise occurs independently among many pixels, the dark noise corresponding to the 2 pixel signal is dominantly produced by dark noise associated with the cross-talk effect. The cross-talk probability can therefore be obtained as the ratio of dark noise rates with 1 and 2 or more pixel signals fired. The cross-talk probability starts at around 0.01, and significantly increases to 0.3–0.5 with the over-voltage, however the temperature does not produce any effect.

The measurement of the relative PDE between the MPPC and a photomultiplier (with Q.E. 15%) is performed with the setup shown in Fig. 7. The LED light pulse is collimated with a 0.5 mm-ϕ pin hole and injected into both the MPPC and the photomultiplier. The results are shown in Fig. 8. PDE goes up with over-voltage, and typically equal to or 1.5–2 times larger than the quantum efficiency of the photomultiplier. Since larger pixel MPPCs have a fractionally smaller insensitive region, the 100 pixel MPPC has a better PDE than the 400 and 1600 pixel MPPCs.

A precise scan of a MPPC's pixels with green YAG laser (wavelength = 532 nm, laser spot size = 1 μm has been performed. Results for a 1600 pixel MPPC are shown in Fig. 9. We have tested all the three types of MPPCs, and variation of photon sensitivity and the gain are found to be less than 5%.

3. Summary and prospects

We have developed and studied the Multi Pixel Photon Counter. Some basic properties are measured and it is confirmed that the MPPC has satisfactory performance for many applications, not only for high energy physics experiments [3–5] but also for some other fields, such as medical engineering systems.

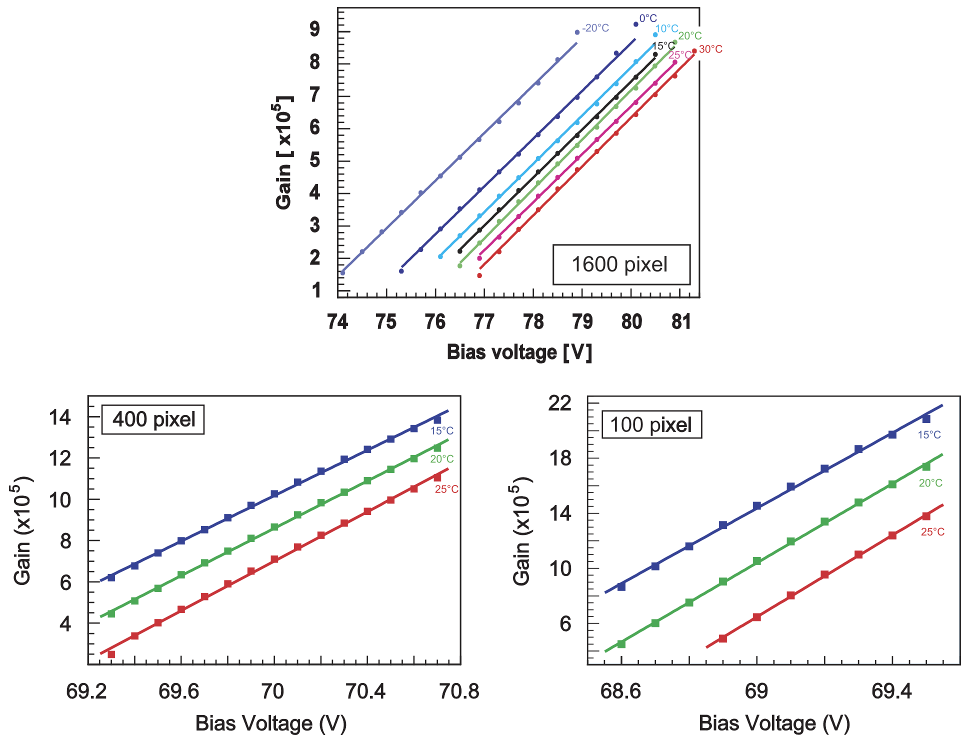

Fig. 3. The results of the gain measurement.

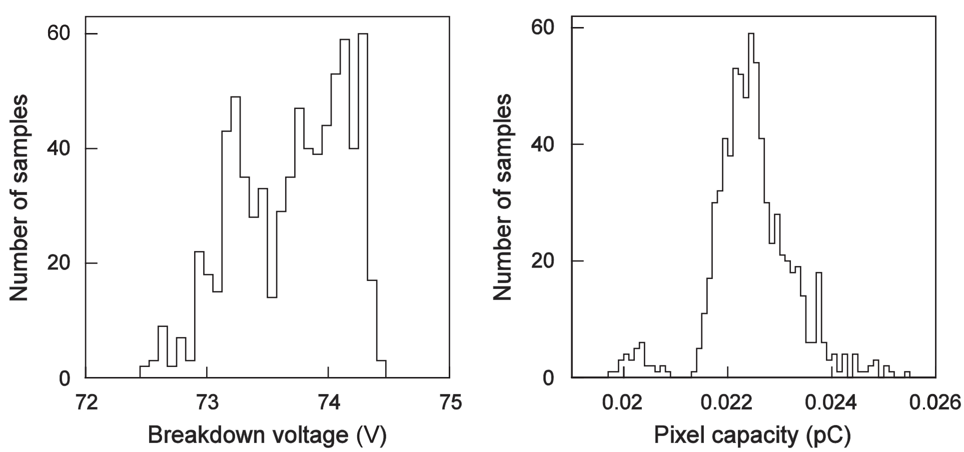

Fig. 4. Variation of the breakdown voltage and pixel capacitance among 750 MPPCs.

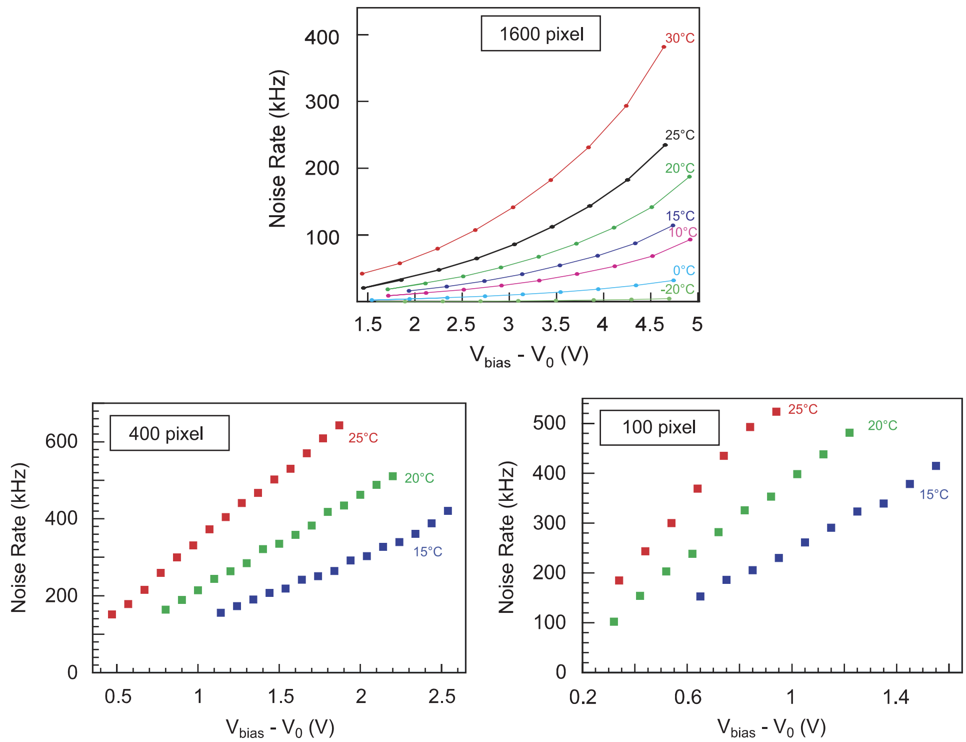

Fig. 5. The rate of dark noise rate caused by thermions.

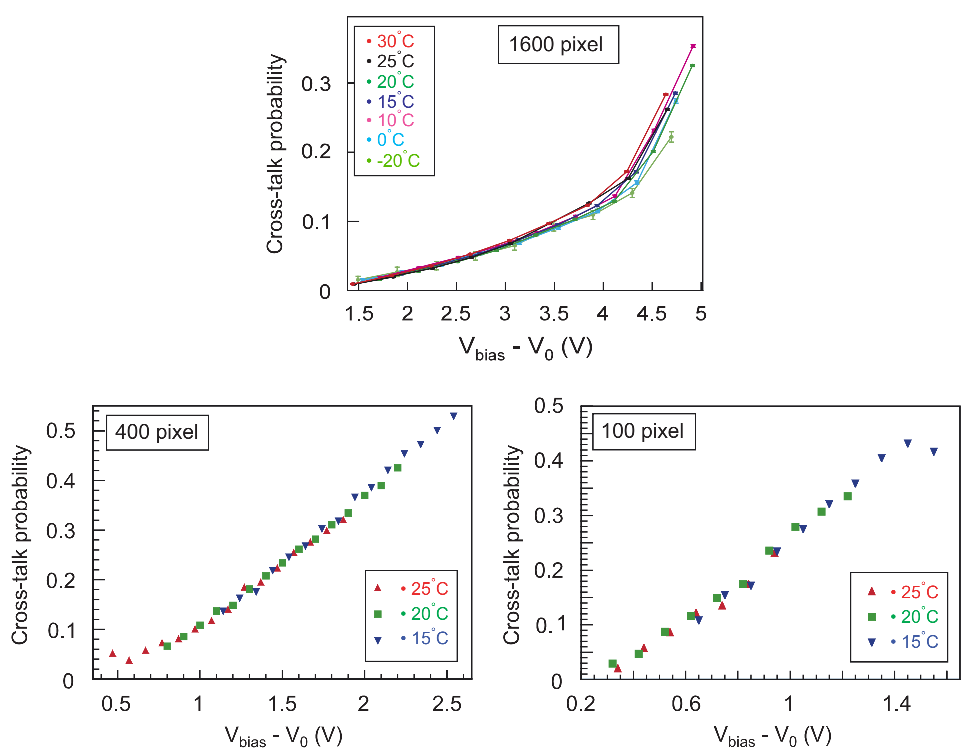

Fig. 6. The cross-talk probability measured from dark noise rates.

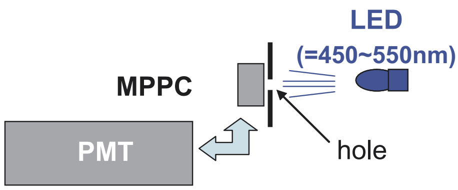

Fig. 7. A setup for the measurement of the relative PDE.

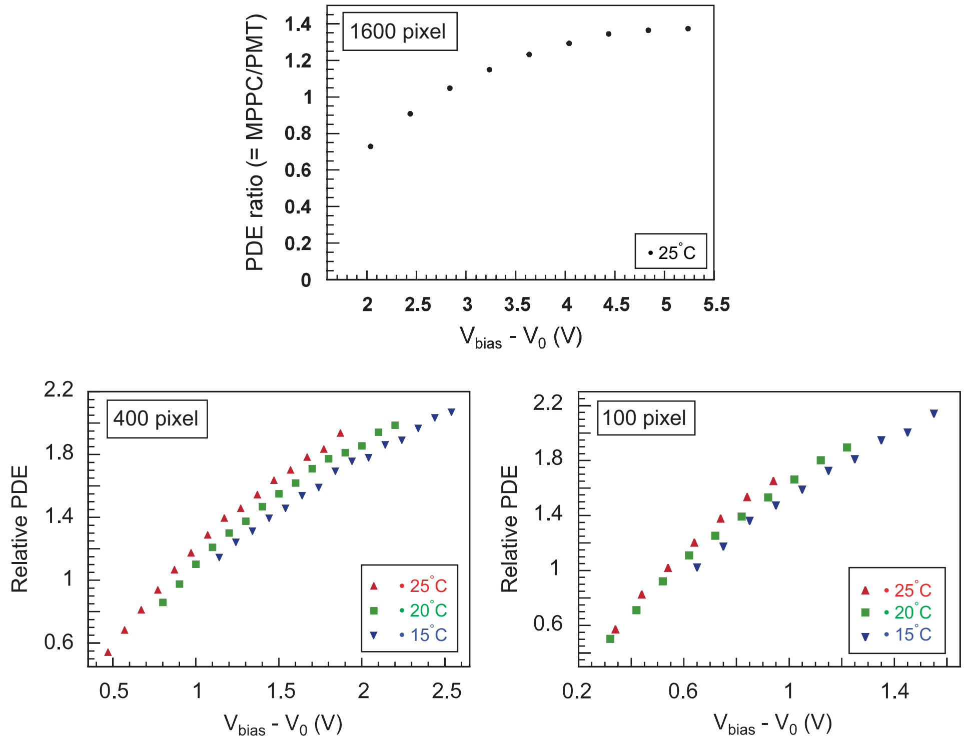

Fig. 8. Observed relative PDE of the MPPC with the hotomultiplier.

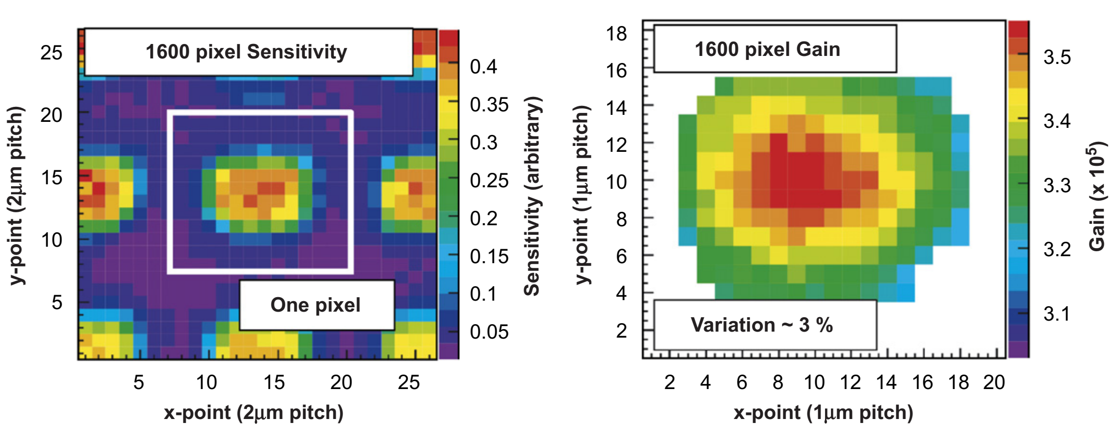

Fig. 9. A result of precise laser scan for 1600 MPPC pixel. Left plot shows sensitivity to photons, and right plot is variation of the gain within a sensitive region in a pixel.

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