Study of MPPC Performance for the GLD Calorimeter Readout

Satoru Uozumi *for the GLD Calorimeter Group*

Shinshu University - Faculty of Science
3-1-1 Asahi, Matsumoto, Nagano 390-8621 Japan

The Multi Pixel Photon Counter (MPPC) is a semiconductor photon sensor which has a multi micro-APD pixel structure which works in limited Geiger mode. Since the MPPC has many attractive features, such as good performance, low cost, compact size and tolerance for magnetic fields, we are developing and studying it, aiming to use it for the scintillator-strip calorimeter readout for the GLD detector. As a result of this study, we have found that the latest 1600 pixel MPPC has satisfactory performance and is feasible for calorimetric use. However further study and development are still needed and are in progress, especially with regards to dynamic range, robustness and radiation hardness.

1 Introduction

The Multi Pixel Photon Counter (MPPC)[1][2] is a semiconductor photon sensor which is one of the Pixelated Photon Detectors (PPD) family, similar to the Silicon Photomultiplier or MRS-APD [3]. As shown in Figure 1, it has multi micro-APD pixels which work in limited Geiger mode. If a photon is injected into a pixel and creates a photoelectron, an avalanche is induced in the strong electric field and is read as a signal. Since the MPPC has many attractive features, such as low cost, compact size and tolerance for magnetic fields, we are developing and studying the 1600 pixel MPPC aiming to utilize it as the readout sensor of the GLD scintillator-strip calorimeter[4].

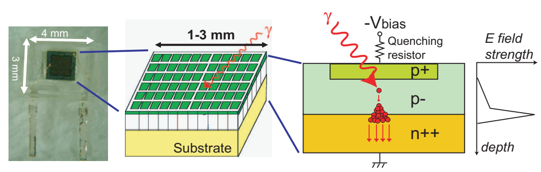

Figure 1: Picture and structure of the MPPC.

2 Performance of the 1600 pixel MPPC

2.1 Gain, Dark Noise Rate, Inter-pixel Cross-talk

The basic performance of the MPPC – gain, dark noise rate and inter-pixel cross-talk probability – are summarized in Figure 2. The gain is measured as function of bias voltage and fitted by a linear function Gain $= C(V_{\text{bias}} - V_0)/e$, where C and V_0 denote the pixel capacitance and breakdown voltage, and e is the electron charge. The quantity $V_{\text{bias}} - V_0$ is the over-voltage and is denoted as ΔV. In the plot one can see that the breakdown voltage depends on temperature with a coefficient $\Delta V_0/\Delta T = 56$ mV$/K$. The gain is typically of order a few 10^5, which is large enough for the requirements of the GLD calorimeter. The dark noise rate and the inter-pixel cross-talk probability are measured as functions of the over-voltage. The dark-noise is caused by thermal electrons, and thus has a strong temperature dependence. Typical values of the dark noise and cross-talk probability are of order 100 kHz and ~0.1 respectively, acceptably small for the GLD calorimeter readout.

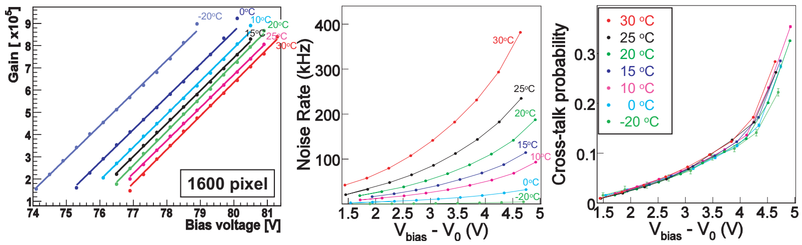

Figure 2: Measured gain, noise rate, inter-pixel cross-talk probability of the 1600 pixel MPPC, as a function of over-voltage and temperature.

2.2 Photon Detection Efficiency

The photon detection efficiency (PDE) of the 1600 pixel MPPC is measured as shown in Figure 3. The LED light pulse is collimated and injected into both the MPPC and Photomultiplier, and its light yield is measured by both sensors. From the ratio of observed light yields and the PDE of the photomultiplier, one can extract the PDE of the MPPC. The measured PDE is also shown in Figure 3. It is observed that PDE increases with over-voltage, and saturates at around 17%. Since the geometrical acceptance of photo-sensitive region of the 1600 pixel MPPC is ~20%, this number is considered to be reasonable. The PDE of 17% is comparable with conventional photomultipliers and is satisfactory for the requirements of the GLD calorimeter.

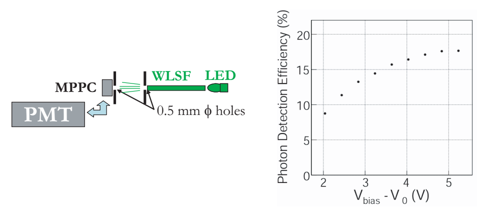

Figure 3: Setup and result of the measurement of photon detection efficiency.

2.3 Recovery Time

The recovery time of the MPPC is another interesting property to measure. The setup and result of the recovery time measurement is shown in Figure 4. Two successive light pulses from a laser and LED are injected with a delay of Δt, and by measuring the pulse height of the MPPC for the second light pulse at different Δt, the recovery of the MPPC can be observed. The right plot in Figure 4 shows the recovery fraction (f_r) measured as a function of Δt. By fitting the measured points with an empirical function $f_r = A(1 - e^{-(\Delta t - b)/\tau})$, the recovery time τ is measured to be $\tau = 4.1 \pm 0.1$ ns. This number is consistent with the CR time constant of the quenching resistor and pixel capacitance.

2.4 Response Function

The MPPC has a non-linear response to input light strength, since in principle each pixel can count only one photon. However since the recovery time of the 1600 pixel MPPC is

$\sim$4 ns, similar to the width of the light pulse from plastic scintillator, light created by a charged particle crossing the scintillator can fire an identical pixel several times. Due to this effect the dynamic range of the MPPC, basically determined by the number of pixels, can be enhanced. We have measured the actual response of the MPPC as a function of the true number of photoelectrons, as shown in Figure 5. In this measurement, PMT is used to determine the number of photoelectrons from the LED. In the result one can see that the shape of response function changes with the duration of the input pulse. This enhancement may be useful for calorimetric use, where a large dynamic range is needed. However a precise determination of the input light pulse is necessary to take advantage of this effect.

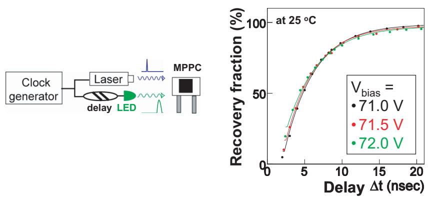

Figure 4: Setup and result of the recovery time measurement. Recovery fraction is ratio of responses for 2nd pulse, measured after a delay of Δt and after complete recovery ($\Delta t = \infty$).

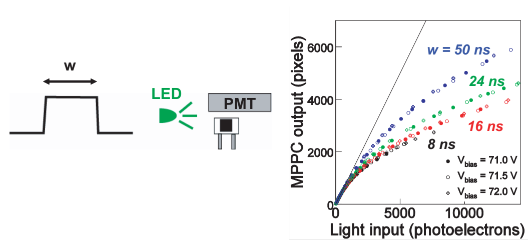

Figure 5: Setup and result of the response function measurement.

3 Summary

We are studying and developing the 1600 pixel MPPC with Hamamatsu Photonics, aiming to utilize it for the GLD calorimeter readout. Results of the several measurements performed so far show satisfactory performance for the GLD calorimeter readout. However development is still underway, and further studies on stability, robustness, and radiation hardness will be performed. The dynamic range and temperature dependence of V_0 will also be improved in the near future.

References

[1] Hamamatsu Photonics K.K.
http://jp.hamamatsu.com/products/sensor-ssd/4010/index_en.html

[2] Satoru Uozumi *for the KEKDTP photon sensor group*, "Development and Study of the Multi Pixel Photon Counter", proceedings for the 10th Vienna Conference on Instrumentation, Vienna, 19-24 Feb 2007.

[3] G. Bondarenko *et al.*, Nucl. Phys. Proc. Suppl. **61B**, 347 (1998); G. Bondarenko *et al.*, Nucl. Instrum. Meth. A **442**, 187 (2000); P. Buzhan *et al.*, ICFA Instrum. Bull. **23**, 28 (2001); P. Buzhan *et al.*, Nucl. Instrum. Meth. A **504**, 48 (2003).

[4] GLD Detector Outline Document, GLD collaboration
http://ilcphys.kek.jp/gld/documents/dod/glddod.pdf