PROCEEDINGS OF SCIENCE

Research and development of MPPC for T2K experiment

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Multi-Pixel Photon Counter (MPPC) is chosen as the photo-sensor for the near detectors in the T2K long baseline experiment, which will start in 2009. As a preparation for the mass production, we have tested 300 MPPCs to study the device-by-device variation of basic performances. A test system is developed to measure 32 devices at the same time. It is found that the variation of MPPC performance is satisfactory small for T2K.

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1. Introduction

The T2K (Tokai-to-Kamioka) experiment is a next generation long baseline neutrino oscillation experiment which will start in April 2009. The main goals in the first phase of T2K are the discovery of ν_e appearance and an accurate measurement of $\nu_\mu$disappearance. In the near detector and neutrino monitor, about 60,000 channels of plastic scintillator read out with wavelength shifting (WLS) fibers will be used. Because the near detector is placed inside a 0.2 T magnetic field with severe space constraint, we need a photosensor that is compact, low-cost, insensitive to magnetic field and has high photon detection efficiency. The multi-pixel photon counter (MPPC) has advantages that match the T2K requirements and is chosen as the photo-sensor for the T2K near detector.

As a preparation for the mass production that will start in JFY 2007, we have tested 300 MPPCs produced by Hamamatsu Photonics. All of them are S10362-11-050CK, which has 1×1 mm^2 active region and 50 μm pitch pixel (400 pixels in a device). A measurement system is developed so that 32 MPPCs can be tested at once. We have measured the basic performances and checked the device-by-device variation.

2. Set up of measurement

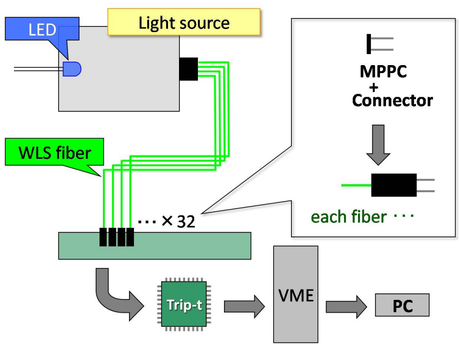


Figure 1: Schematic drawing of the measurement setup. Thirty two MPPCs can be measured at the same time using a board with Trip-t ASIC chip. WLS fiber is connected to MPPC by using a plastic connector.

Figure 1 shows a schematic drawing of the measurement set up. Light from a blue LED is defused by two translucent plastic plates and fed to MPPCs via WLS fibers. We use Kuraray Y11(200)MS fibers with 1.0 mm diameter, which is the same type as that will be used in T2K. The WLS fiber and MPPC are connected using a plastic connector developed by our group [1]. Signals from MPPCs are read out using a custom electronics with Trip-t ASIC chip [2]. Trip-t, originally developed at Fermilab, can read out 32 channels and will be used in T2K near detectors. The output charge from MPPC is digitized using 12-bit ADC.

3. Measurement results

We measure the gain and the photo-detection efficiency (PDE) with the light source, while the noise rate and the probability of sum of cross-talk and after pulse are measured without light input.

It took 7 days to measure 300 MPPCs, however the necessary time will be reduced in the mass production stage by improvement of procedure and having multiple test setups.

3.1 Gain and breakdown voltage

The gain of MPPC linearly depends on the applied voltage V_{bias} as

$$\text{Gain} = \frac{C}{e}(V_{\text{bias}} - V_{\text{bd}}), \tag{3.1}$$

where C is the capacitance of the single APD pixel and e is the absolute of an electron charge. The breakdown voltage V_{bd} is the threshold voltage above which MPPC operates in the Geiger mode. V_{bd} can be derived by linearly extrapolating the measured gain-voltage curve to the point where gain becomes zero. Most of basic parameters of MPPC are known to depend on the difference between the applied voltage and the breakdown voltage, $\Delta V \equiv V_{\text{bias}} - V_{\text{bd}}$ [3]. ΔV is called the over voltage. Thus, V_{bd} and ΔV are important parameters to characterize the performance of MPPC.

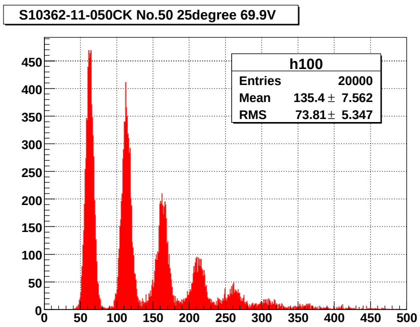


Figure 2: ADC Distribution of MPPC output.

From the measured ADC counts (Fig. 2) between the pedestal peak and one photo-electron (PE) signal peak, we can calculate the charge of a single fired pixel, Q. The gain is defined as Q divided by e. Figure 3 shows the measured gain at $20°C$ as a function of the over voltage, for 300 MPPCs. Figure 4 shows the distribution of gain at $\Delta V = 1.5$ V, which is the candidate operation voltage at T2K. The RMS of the gain distribution at $\Delta V = 1.5$ V is about 6%.

Figure 5 is the distribution of the single pixel capacitance divided by e, which is derived as the slope of gain-voltage relation (Eq. 3.1). The RMS of the distribution is about 5%. Figure 6 is the distribution of V_{bd}. 94.6% of devices have V_{bd} within 1 V of variation and all are within 2 V. This variation is well within the adjustable range of applied voltage with planned T2K electronics.

3.2 Photon detection efficiency (PDE)

The photon detection efficiency (PDE) is measured using a PMT as a reference. The ratio of observed PE of MPPC to that of PMT is taken as the relative PDE of MPPC. We use a plastic connector for the coupling of MPPC and fiber. Therefore, the PDE measured here includes the effect from this optical coupling, which reflects the real situation at the experiment.

Figure 7 shows the measured PDE as a function of ΔV. The PDE of MPPC is 1.5–2.2 times that of PMT at $\Delta V = 1.5$ V. The RMS of PDE for 300 MPPCs is about 10%. Again, note that

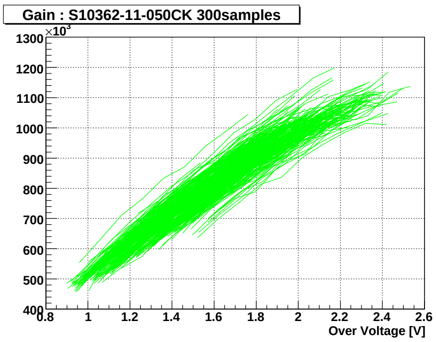


Figure 3: Measured gain as a function of over voltage for 300 MPPCs.

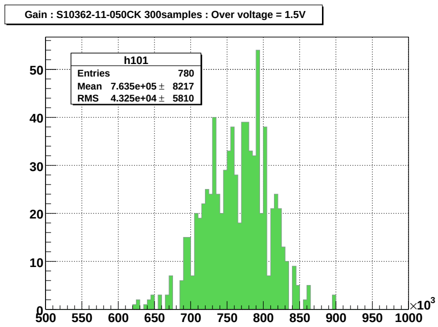


Figure 4: Measured gain at $\Delta V = 1.5$ V.

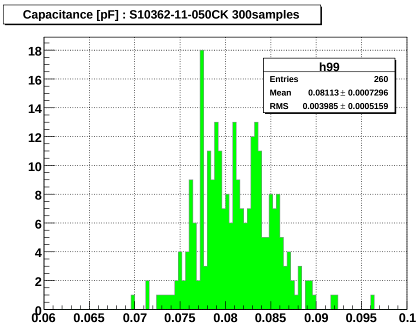


Figure 5: Capacitance/e

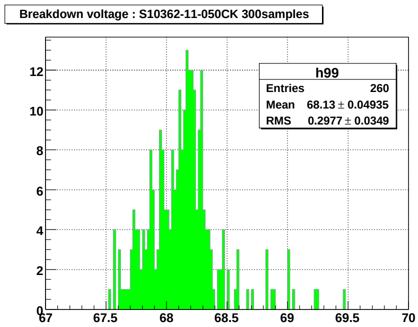


Figure 6: Breakdown voltages

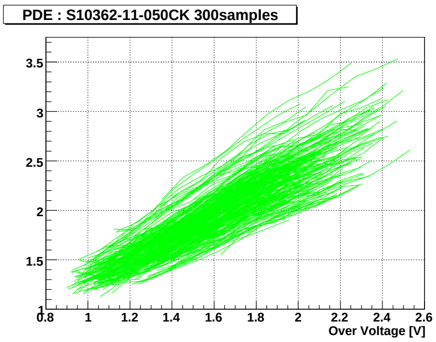


Figure 7: PDE vs ΔV.

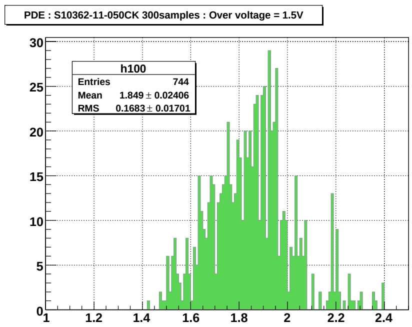
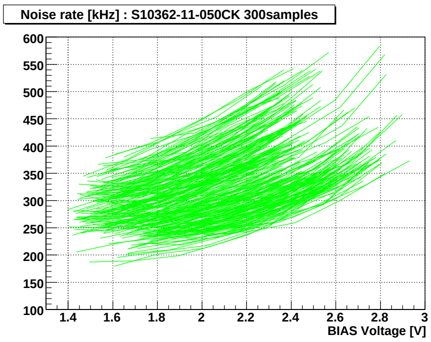


Figure 8: PDE at $\Delta V = 1.5$ V.

this variation includes the effect from the variation of optical coupling, in addition to the device themselves.

3.3 Noise rate

We measure the noise rate by using ADC distribution with random triggers. In order to avoid effects of cross-talk and after pulse, the number of noise events is estimated from the number of pedestal events assuming Poisson distribution.



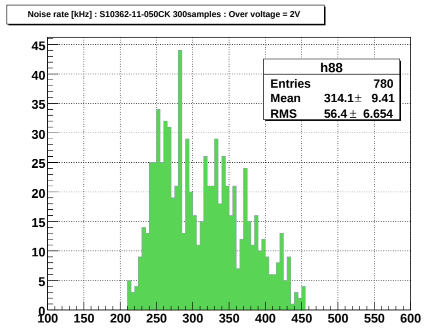


Figure 9: Noise rate as a function of ΔV.

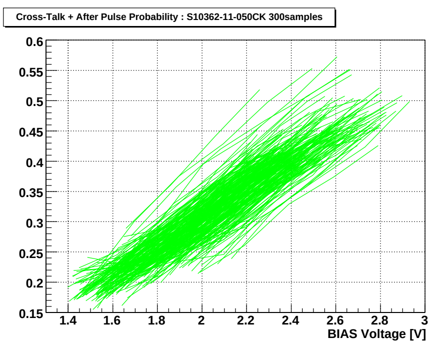
Figure 10: Noise rate at $\Delta V = 2.0$ V.

Figure 9 and 10 show the measured noise rate as a function of ΔV and at $\Delta V = 2.0$ V, respectively. The RMS of the noise rate is about 18%. The noise rate is found to have larger variation than other parameters.

3.4 Probability of cross-talk and after pulse

The MPPC is known to have optical cross-talk between APD pixels, that makes an extra charge in addition to the one due to the original Geiger discharge. Alter-pulse, which results from trapping and releasing of charge from defects, is another cause of an additional charge. In both cases, the extra charge is produced by Geiger discharge and thus the amount of charge is the same as the original signal.

We measure the inclusive probability of cross-talk and after pulse using the ADC distribution. The number of 'true' one PE events is estimated from the number of pedestal events assuming the Poisson distribution. Comparing it with the observed number of one PE events, we can estimate the fraction of events that have additional charge. This fraction is considered as the probability of cross-talk and after pulse.



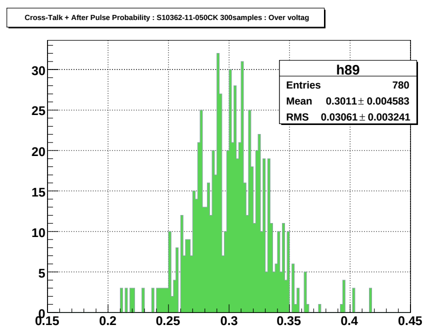


Figure 11: Probability of the sum of cross-talk and after pulse as a function of ΔV.

Figure 12: Probability of the sum of cross-talk and after pulse at $\Delta V = 2.0$ V.

Figure 11 and 12 show the results as a function of ΔV and at $\Delta V = 2.0$ V. The RMS of the distribution is about 10%.

3.5 Summary of measurements

Item	Requirements for T2K	Results (RMS)
Gain	$> 5 \times 10^5$	7.3–8.5 $\times 10^5$ (6%)
PDE	$>$PMT	1.7–2.2$\times$PMT (10%)
Noise rate	$<$ 1 MHz	200–400 kHz (18%)
Cross-talk + After pulse	$\sim$10%	13–22% (10%)

Table 1: Summary of measurements for 300 MPPCs (S10362-11-050CK).

The results are summarized in Table 1. Both the variation and absolute values of performance are satisfactory for T2K. Although the variation of noise rate is larger than other parameters, it is well below the requirement. The probability of cross-talk and after pulse is larger than the original requirement. It desired that these performances are improved in the future development, but it is usable level for T2K.

4. Conclusion

We have tested 300 MPPCs to study basic performances and to check the device-by-device variation. A measurement system is developed to test 32 devices in parallel. It is found that the variation of MPPC performance is satisfactory small.

Acknowledgements

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References

[1] H. Kawamuko *et al.*, in these proceedings.

[2] T. Murakami, *et al.*, in these proceedings.

[3] Makoto Taguchi, “*Development of Multi-Pixel Photon Counters and readout electronics*,” Master’s thesis, Kyoto University (February 2007).