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New gated MCP-PMTs and their performances in comparison with semiconductor type detectors for SLR applications

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Abstract

MCP-PMTs (Microchannel Plate Photomultiplier Tubes) and semiconductor detectors such as APD (Avalanche Photo Diode) are commonly used for SLR applications. Performances of these detectors are compared on parameters such as sensitivity, noise, temporal response, timing jitter and other characteristics. The MCP-PMTs we have developed show improvements in especially sensitivity and noise induced by gating pulse.
We also focus on signal processing technic to optimize detector performance and introduce other possible detector modules for future applications. Other possible applications using MCP-PMTs are discussed as well for general laser ranging.

1. Introduction

New Gated MCP-PMTs introduced herein have been greatly improved in their performances compared to the previous type, R5916U series. In particular, sensitivity (= detection efficiency in this case) and time resolution are superior to the R5916U series. In comparison with semiconductor type detector, the new gated MCP-PMT units show some advantages on their performances. In this paper, characteristics of the new gated MCP-PMT units are discussed in comparison with R5916U series and semiconductor detector.

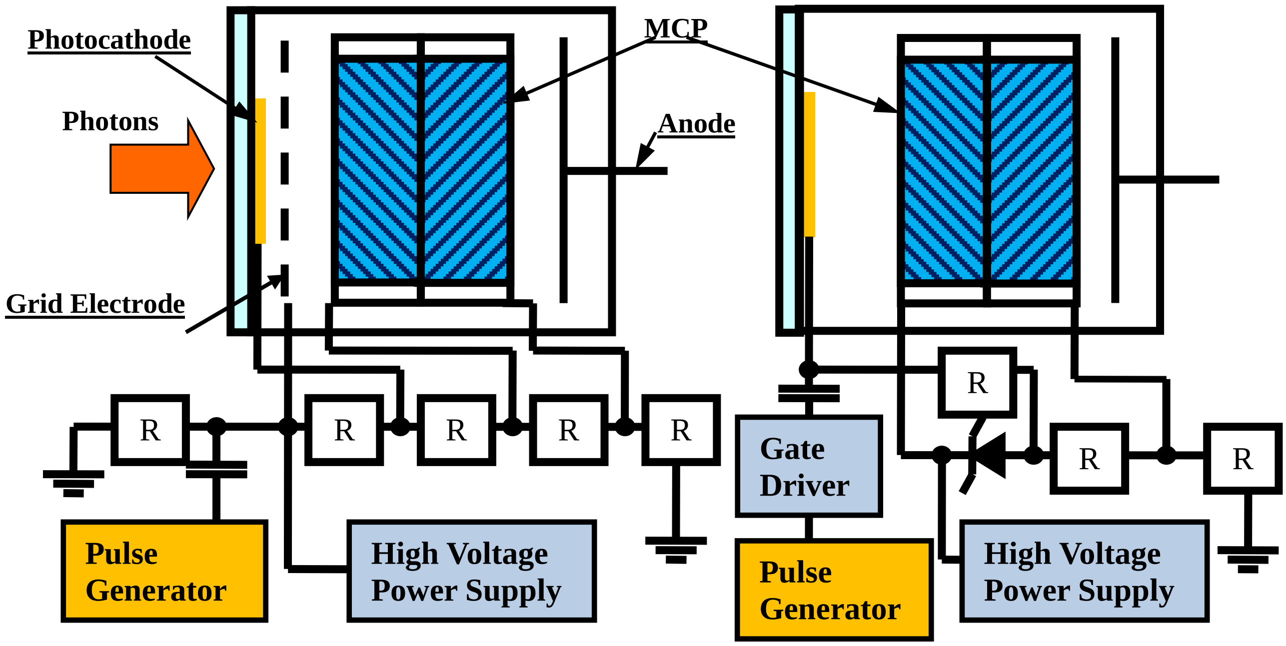
2. Improved performances in comparison with former type (Hamamatsu R5916U series)

2-1. Structures and operating principles

Figure 1 shows structures and operating principles of previous type, R5916U series and new gated MCP-PMT. R5916U has a grid electrode between the photocathode and MCP for gating function but new type does not. In a case of new type, a gate pulse is directly applied to the photocathode instead of the grid electrode. This structure has resulted in improvements of detection efficiency (DE) and time resolution. DE has been improved for 30% or so and the time resolution as well (as shown in Figure 2).

The grid electrode blocks some photoelectrons passing through and also generates some time jitter caused by low potential due to the gate pulse (10 to 50 V but 200 V with the new type).

Figure 1. Structures (Sensor Head) & operating principles of R5916U series on the left and new type on the right



2-2. Time Resolution

New gated MCP-PMT units show a great improvement in time resolution over R5916U series. R5916U series poses a grid electrode for gating operation and require generally commercialized pulse generator instead of exclusive gate power supply which new type requires. Because the grid electrode is placed quite closely to the photocathode, it is not necessary to apply such a high voltage but just 10 V to drive the gating operation. However, low potential between the grid electrode and photocathode causes a time jitter.

A best choice of the photocathode in terms of time resolution is alkali type photocathode. Time resolution of crystal type photocathode is not as good as that of alkali type photocathode. Time resolution is greatly influenced by a thickness of photocathode layer. Thicker one has more time jitters than thinner one. Crystal type photocathode shows higher sensitivity than alkali type but deteriorate time resolution a little due to the photocathode layer which is thicker than alkali metal layer.

A block diagram of measuring apparatus for time resolution is indicated in Figure 2. This set-up is known as TCSPC which stands for time correlated single photon counting. As a result, it gives a time distribution of a set pulses each of which corresponds to the MCP-PMT transit time for that individual event (=electron multiplication). This is defined as FWHM (Full Width at Half Maximum).

Figure 2. Block diagram of measuring apparatus for time resolution
New Gated MCP-PMT Unit consisting of MCP-PMT, HVPS and Gate Driver & Power Supply
Laser Diode:#PLP-01(410nm/35 ps @FWHM)/Hamamatsu,
Pulse Generator: #8110A/Hewlett Packard, Preamp: C5594/Hamamatsu, Attenuator: Tektronix,
Delay Unit: #425/EG&G Ortec, CFD: #TC-454/Tenelec(Canberra). TAC: #457/ EG&G Ortec
MCA: #E-552A,562A,563A/NAIG

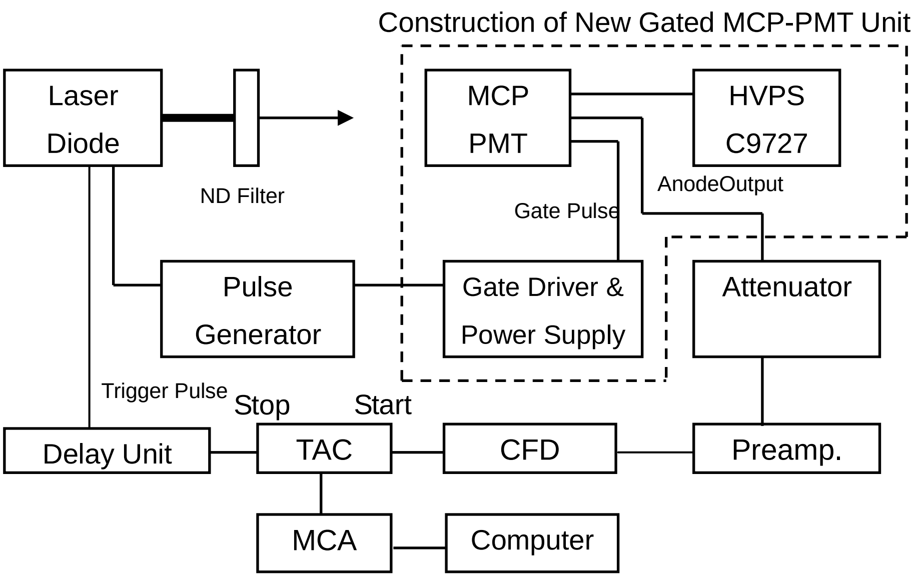
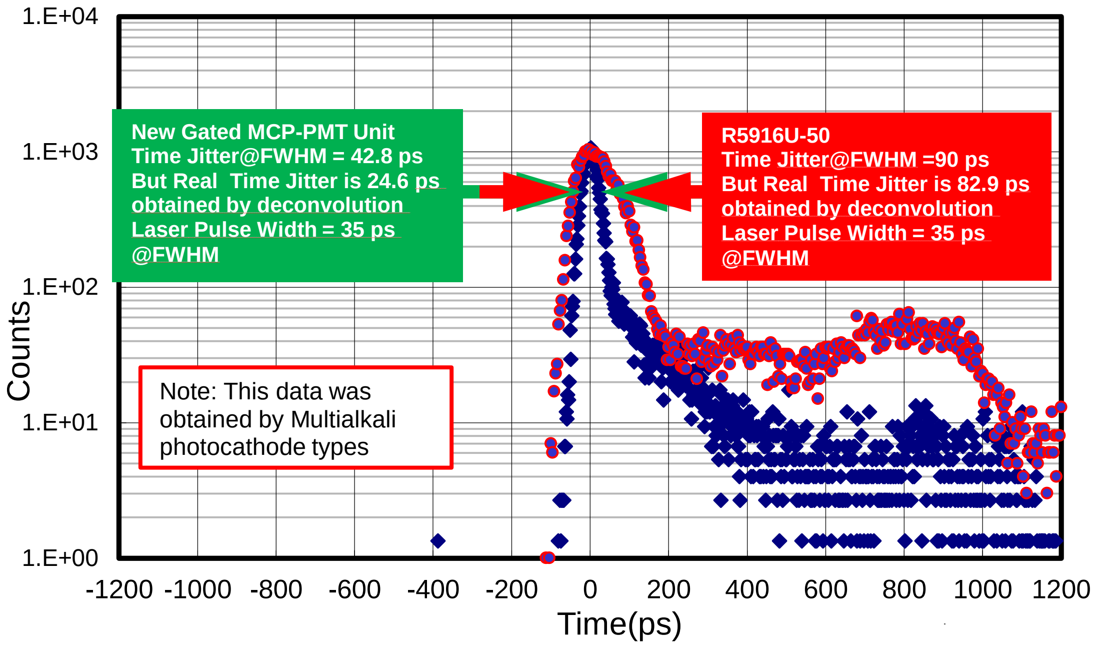


Figure 3. Time Resolutions
Time distribution of a set pulses each of which corresponds to the MCP-PMT transit time for that individual event (=electron multiplication)



2-4 Photocathode Sensitivities and Detection Efficiency

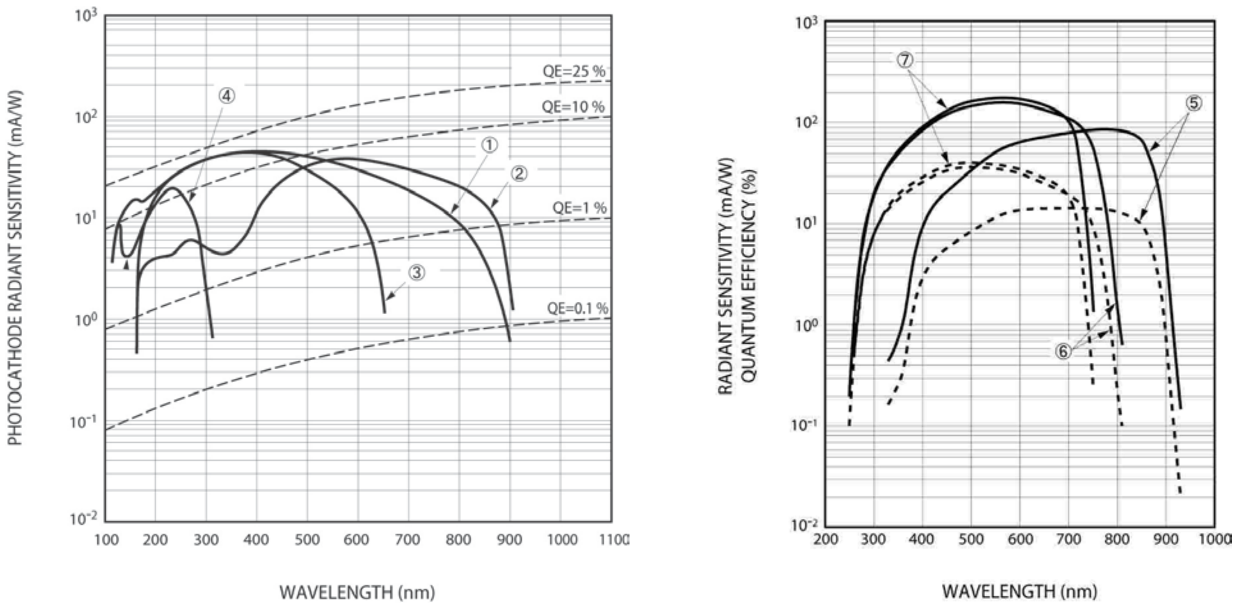
Figure 4 shows spectral response characteristics indicating radiant sensitivities and quantum efficiencies. Seven kinds of photocathode are available with new gated MCP-PMT unit. GaAsP is the best suited photocathode for a wavelength of 532 nm. This is a frequency doubled of near infrared light originated by Nd:YAG laser which is generally used for SLR.

All photoelectrons converted by photocathode do not reach anode as a signal output. There are a grid electrode (metal mesh; R5916U series only) and MCP on photoelectron trajectory. These parts make some loss of photoelectron. A probability of loss can be estimated by the open-area-ratio (OAR) of each part. Each OAR is 60 to 70 %. The detection efficiency (DE) can be estimated by the following equation;

$$DE = QE * OAR(Grid) * OAR(MCP)$$

New gated MCP-PMT has no grid. Thus, its OAR(Grid) is 100 % instead of 60 to 70 % with R5916U series.

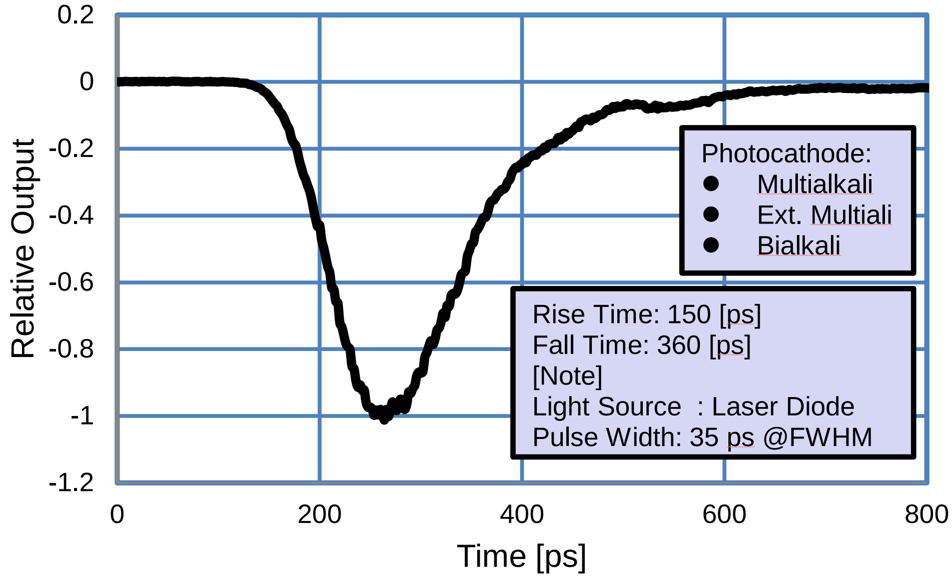
Figure 4. Spectral response curves of alkali metal type photocathode on left and crystal type on right. ①Multialkali. ②Extended Multialkali, ③Bialkali
④Cs-Te, ⑤GaAs, ⑥Extended GaAsP, ⑦GaAsP



2-5. Output Waveform

Impulse response of the new gated MCP-PMT is shown in Figure 5. This was obtained with multialkali type. The rise time is roughly 20 % faster (180 ps ⇒ 150 ps) than R5916U series and GaAsP type. All alkali types of new gated MCP-PMT basically show quite similar response. However, GaAsP type show roughly 20 %

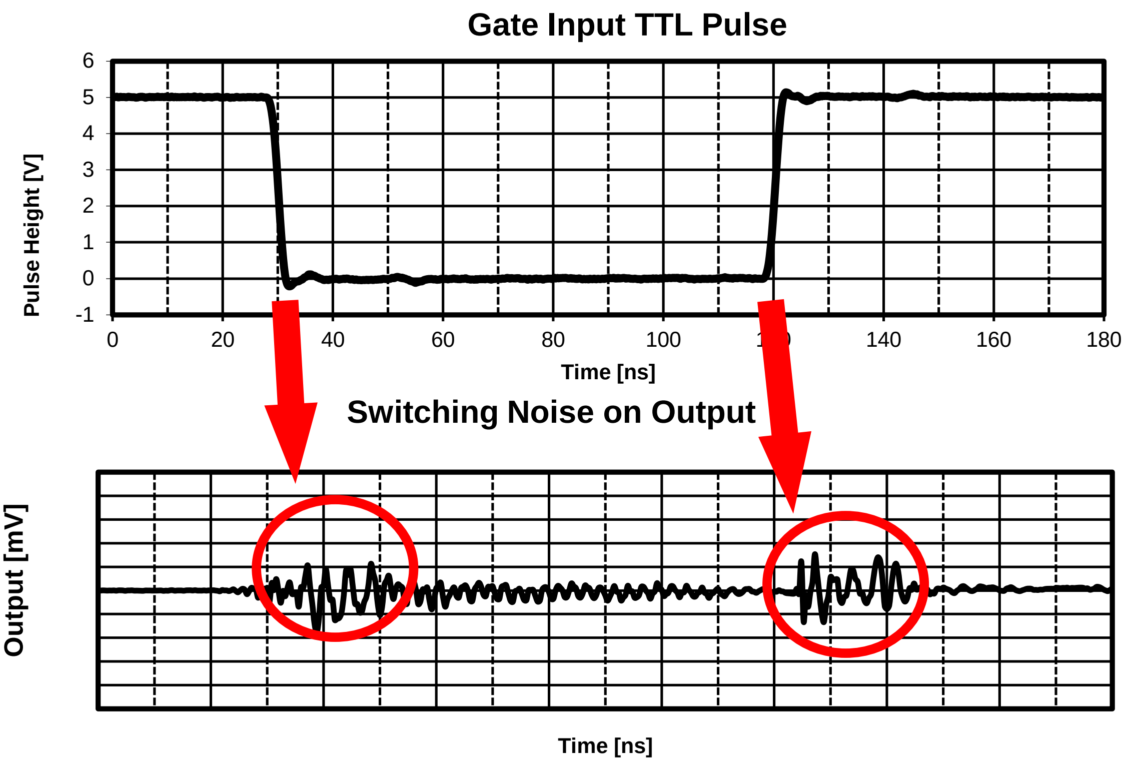
Figure 5. Time response of the new gated MCP-PMT with multialkali photocathode



2-6. Switching Noise Induced by Gate Pulse

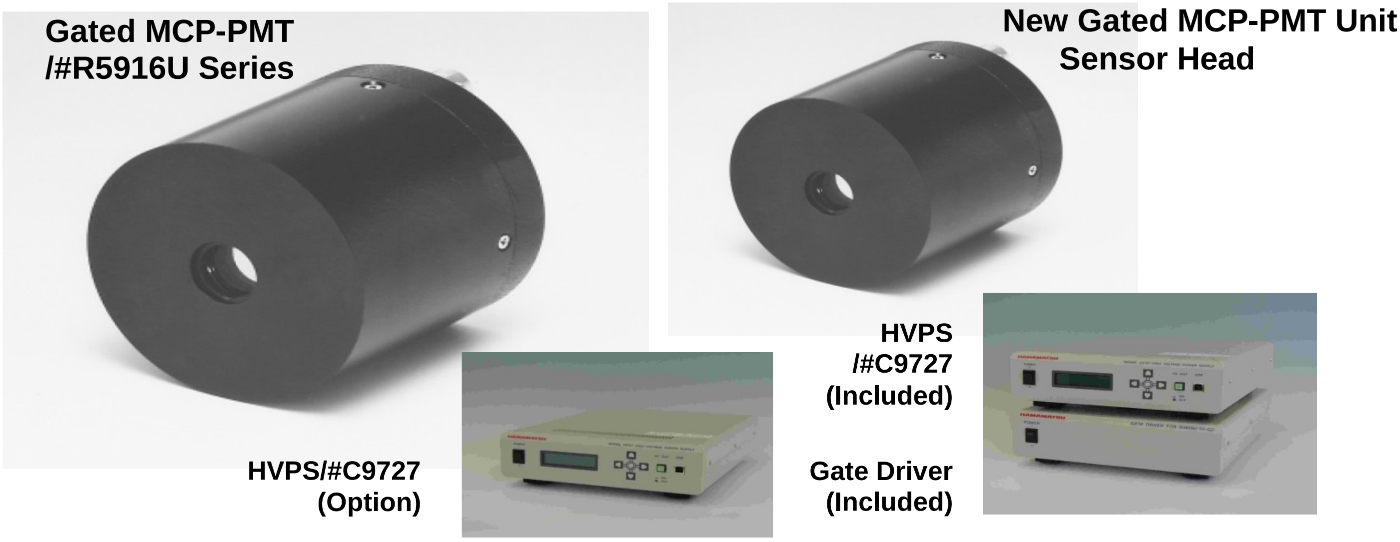
Gate pulse generates a noise on an output of the gated MCP-PMT as shown in Figure 6. This is caused by induction current being transferred from photocathode to anode. We have reduced the noise level successfully by improving gating and voltage divider circuit,

Figure 6. Gate Input Pulse and Switching Noise
Noises appear when the gate input TTL pulse raises and falls.



2.7 Photographs of the new gated MCP-PMT unit and R5916U

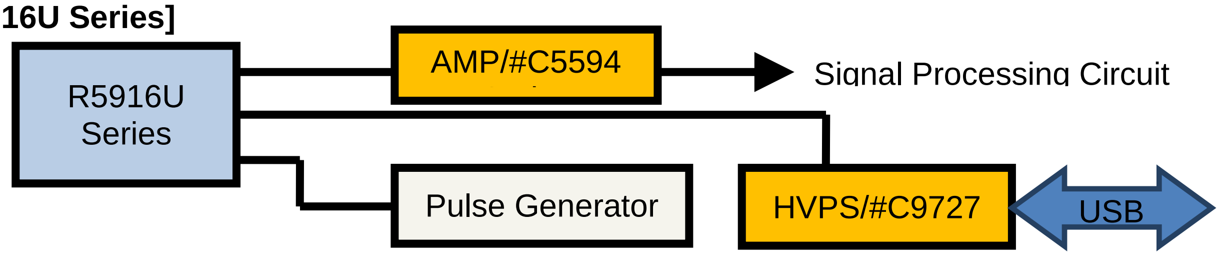
New gated MCP-PMT unit consists of a MCP-PMT sensor head, HVPS (high voltage power supply) and gate driver but R5916U series do not include HVPS and not require any gate driver. Both types require a pulse generator with TTL for the new types and 10 to 50 V pulse height for R5916U series.



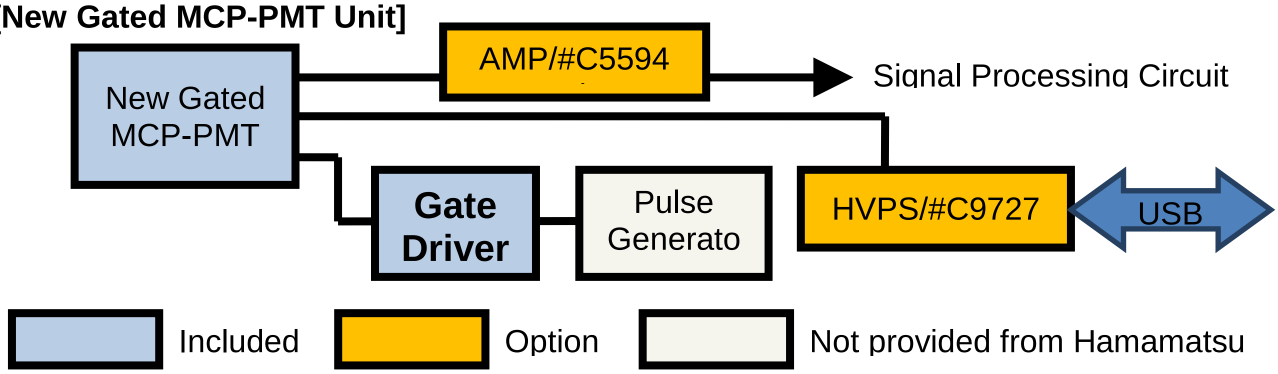
2.8 Wiring for Set-up

Block diagrams for wiring are as follows;

[R5916U Series]



[New Gated MCP-PMT Unit]



3. Comparison with Semiconductor Type Detector

There are two types of the new gated MCP-PMT as listed in Table 1. One has a multialkali type photocathode and the other type has a GaAsP. Multialkali type shows a time resolution of 25 ps (pico-second) or less at FWHM (full width at half maximum), This value corresponds to 7.5 mm as a distance error in laser ranging measurement and is defined under the operating condition of which its photocathode is illuminated by incident light in whole area. If the illumination area can be focused narrower, the time resolution will be improved. GAsP type does not show a time resolution as good as a multialkali type as explained in 2-2. But it has much higher sensitivity than multialkali type at 532 nm.

New gated MCP-PMT of multialkali type has more than twice better time resolution than that of R5916U series and semiconductor detector. However a time resolution of GaAsP type does not show much difference from that of semiconductor detector even though it is better than R5916U series. A sensitivity of GaAsP type is much higher than R5916U of muktualkali type and roughly twice better than semiconductor detector.

All PMT types have much wider photo sensitive area than semiconductor detector. This would make an adjustment of optical alignment much easier on its set-up and maintenance of SLR apparatus.

Table 1. Characteristics

Parameters		R5916U-50 (Multialkali)	New Gated MCP-PMT (Multialkali)	New Gated MCP-PMT (GaAsP)	Semiconductor Detector
Spectral Response Range [nm]		160 - 850	160 - 850	280 - 720	350 - 1100
Quantum Efficiency(QE) [%]@532 nm (Typ.)		8	8	40	20
Effective Area (mm in Diameter)		10	10	10	0.2
Gain (Min.)		1.0×10^5	1.0×10^5	1.0×10^5	-
Time Response [ns] (Typ.)	Rise Time	0.18	0.15	0.18	0.7
	Fall Time	0.7	0.4	0.4	-
Time Resolution (Jitter) @FWHM [ps] (Typ.)		90 [1)]	≦25 [2)]	50 [2)]	< 60
Dark Count Rate $[s^{-1}]$ @25 ℃ (Typ.)		1000	1000	10000	9000
Average Anode Current [nA] (Max.)		100	100	100	-
Gating Time		5 ns -10 μs	100 ns - 50 μs	100 ns - 50 μs	-

1) This value includes a jitter of the electronics and the pulse width (35 ps @FWHM) of the light source.
2) These values are obtained by deconvolution for the laser pulse width.

4. Signal Processing Technique

Time resolution data of all MCP-PMTs were obtained by TCSPC (Time Correlated Single Photon Counting) measurement. A block diagram of the measuring apparatus is indicated in Figure 2. A time resolution of the MCP-PMTs is practically given by estimation calculated from IRF (Instrument Response Function) which was actually measured and laser pulse width. IRF is determined by a convolution of laser pulse width and jitters mainly generated by a detector, electric circuits and laser. CFD (Constant Fraction Discriminator) is in the set-up and one of key device which determines the IRF.

Optimizing CFD is quite important in terms of obtaining best time resolution. The CFD we used is commercialized and provided by CANBERRA. The model number is 454 which is a quad type and has 200 MHz repetition capability. Some of commercialized CFD including 454 require a connection of coax cable for a delay line which is usually placed in the outside of circuit or on the package panel. However, a time response of MCP-PMTs is too fast for most of commercialized CFDs to process its output signals. Therefore, it is often recommended to connect it directly onto the circuit. Time-walk and threshold adjustments are also required for optimization.

5. Conclusion

New gated MCP-PMT units are now our standard product. There are two major selections (multialkali or GaAsP photocathode types) depending on priorities of either time resolution or photocathode sensitivity. Time resolution and sensitivity are trade off. A performance of all new gated types is superior to that of R5916U series.

However, in comparison with semiconductor detector, multialkali type shows much higher time resolution but lower sensitivity, on the other hand, GaAsP type shows higher sensitivity but not so much difference in time resolution. Regarding photocathode effective area, all MCP-PMTs have large advantage over the semiconductor detector.

We will continue to improve a performance to meet uses requirements.

Acknowledgement

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