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LIFETIME OF HPK SQUARE-SHAPE MCP-PMT*

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Development of a new type RICH counter named "TOP counter" for Belle II experiment is reported. The device is based on the MCP-PMT. Progress on the square-shape MCP-PMT used to expand the sensitive region is described. A study of the QE stability of this new MCP-PMT is reported and the ways how to improve its lifetime are explained. New device reaches the lifetime of $2.5\,\mathrm{C/cm^2}$ for the 80% of original QE with the 2.0×106 gain.

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1. Introduction

A new type of the particle identification device, TOP counter, has been developed for the upgraded B factory experiment. The TOP counter performs the PID using the RICH and TOF techniques. The important characteristic of the TOP counter is that the ring image is detected as the relative time difference of photons. Therefore, the time resolution of the TOP counter is very important. The separation power S of PID is roughly evaluated with the following equation

$$S = \frac{\Delta\mathrm{TOF} + \Delta\mathrm{TOP}}{\sigma_{\mathrm{TOP}}} \times \sqrt{N_{\mathrm{det}}}\,, \qquad (1)$$

where the values ΔTOF, ΔTOP, σ_{TOP} and N_{det} are the difference of TOF, the difference of TOP, the time resolution of the TOP counter, and the number of detected photons, respectively.

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2. Lifetime of SL10

The only remaining problem of the square-shape MCP-PMT is the long range performance stability, the lifetime. We have measured the lifetime of MCP-PMTs. In the tests the following devices were used: CT0790, JT0006 and JT0007. The differences of these devices are shown in Table I.

TABLE I

The differences of the measured MCP-PMTs.

Serial No.	CT0790	JT0006	JT0011
Tube Shape	Cylinder	Cube	Cube
Al-layer	1st-MCP	1st-MCP	2nd-MCP

The result is shown in figure 1. It is found that the cylindrical type MCP-PMT has the lifetime longer than $1\,\mathrm{C/cm^2}$ for the 80% of the original quantum efficiency (QE), while for, the square-shape MCP-PMT it is less than $5.0 \times 10^{-2}\,\mathrm{C/cm^2}$. We have studied the difference of the lifetimes of the cylindrical and the square-shape MCP-PMTs.

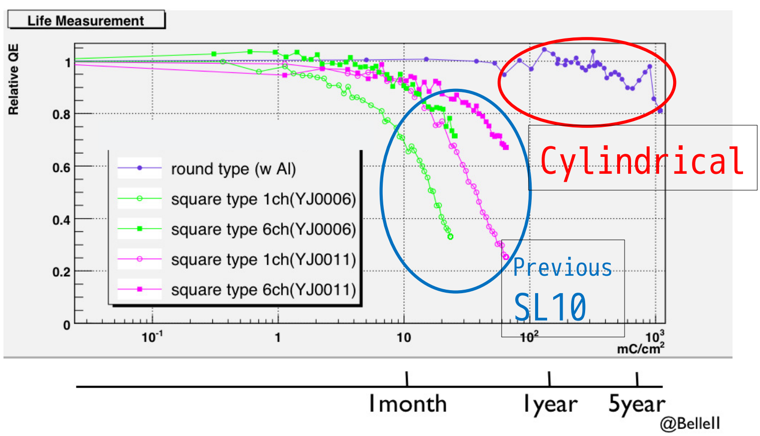


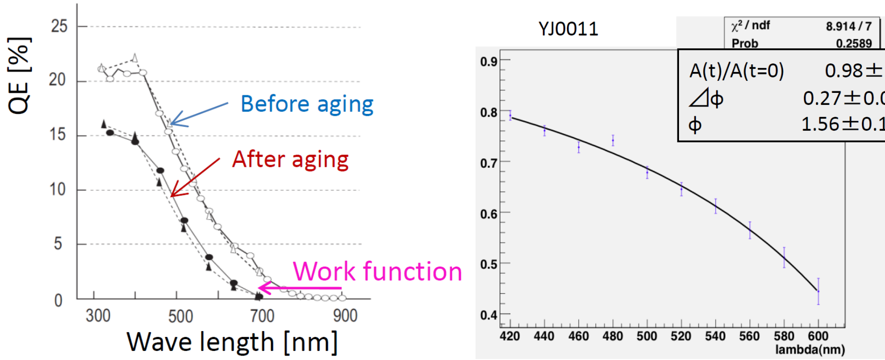
Fig. 1. The relative QE to the output charge per unit area.

3. QE degradation mechanism

The mechanism of the QE degradation is discussed in this section.

3.1. Wavelength dependence of QE degradation

The wavelength dependence of the QE degradation is studied. Figure 2(a) shows the QEs before and after the ageing process as the function of the wavelength. Their ratio is shown in Fig. 2(b).



(a) (b)

Fig. 2. The QEs as a function of the photon wavelength. (a) The QE dependence on the photon wavelength before and after the ageing process. The work function is also presented. (b) The ratio of the quantum efficiency as measured before the ageing process to that after the ageing took place as a function of the photon wavelength.

3.2. Position dependence of QE degradation

The QE as a function of the two-dimensional position is shown in Fig. 3. The degradation of the peripheral parts of the photocathode is strong and in particular much stronger than that observed for the central part.

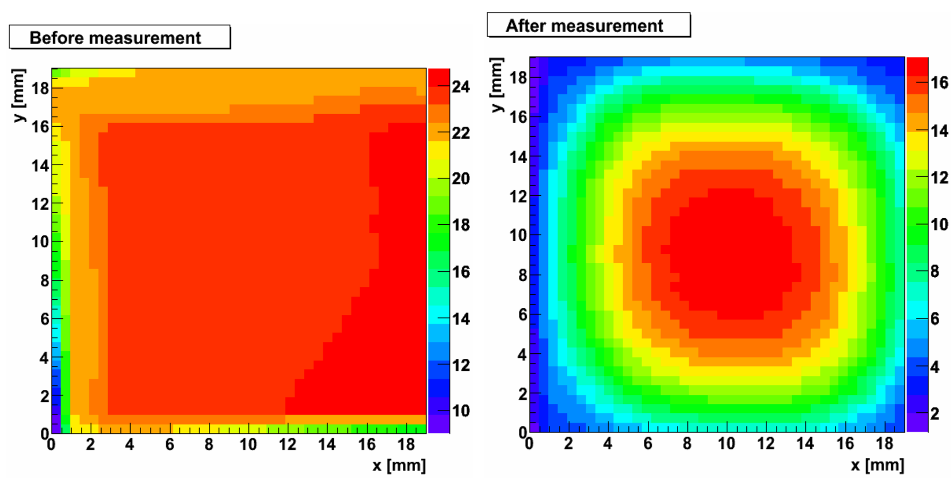


Fig. 3. The position distribution of QE.

One of possible causes of the QE degradation is the ion feedback. However, the ion feedback should lead to a uniform degradation of the QE over the photocathode area. Therefore, a possibility of yet another reason for the observed behaviour has to be taken into account and we considered the influence of the inner structure of the MCP-PMT.

3.3. Inner structure of MCP-PMT

A schematic view of the inner structures of the cylindrical and the square-shape MCP-PMTs is shown in Fig. 4. We have looked into the inner-structures and have found the difference of the implementation of MCPs between two kinds of the MCP-PMTs. To get a larger sensitive region the tube of the square-shape MCP-PMT is made of stainless steel while that of the cylindrical one is made of ceramic. The voltage of the tube is the same as that of the photocathode. Thus, the MCPs should be isolated from the tube. Consequently, there is a gap connecting the space of the photocathode and anode sides. However, there is no such a gap in the case of the cylindrical type. Because of the electric field only electrically neutral entities can traverse the gap freely.

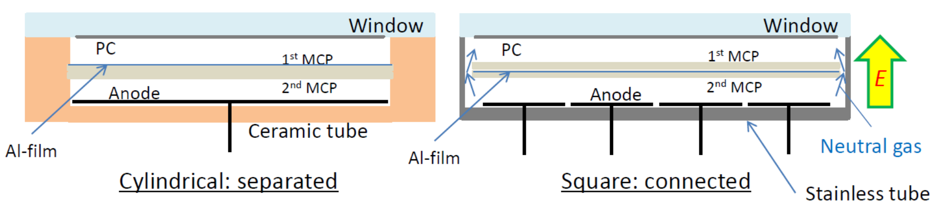


Fig. 4. The inner structures of cylindrical type and square-shape MCP-PMT.

We suspect that the out-gas damages the photocathode. Our suspicions are confirmed in [2,3]. Because of the gap, it is possible that much more out-gas can be released in the square-shape MCP-PMT than in the cylindrical one.

4. New SL10

Suspecting that the predominant source of the QE degradation is the neutral gas, we decided to produce a new SL10s which survive longer than ordinary SL10s. This idea required a modification of the inner structure of the device.

4.1. Modification of inner structure

A ceramic insulator was located in the MCP-PMT as shown in Fig. 5. This allows to close the gap. In addition, the MCPs were exchanged with those of low out-gassing type.

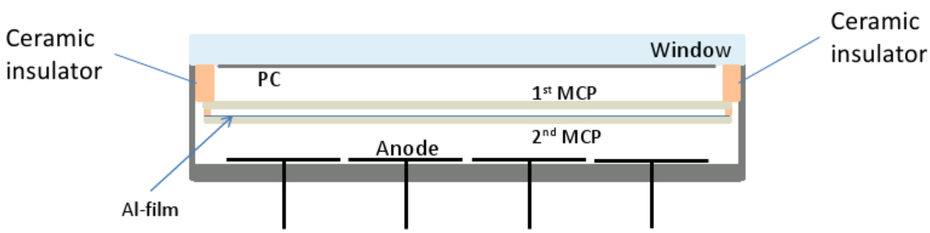


Fig. 5. The inner structure of new SL10.

4.2. Lifetime of new SL10

The lifetime of new and old SL10s devices is compared in Fig. 6. As was expected the construction modification resulted in the device lifetime increase. It was found that the new SL10 has the lifetime of 2.5 C/cm^2 for 80% of the original QE.

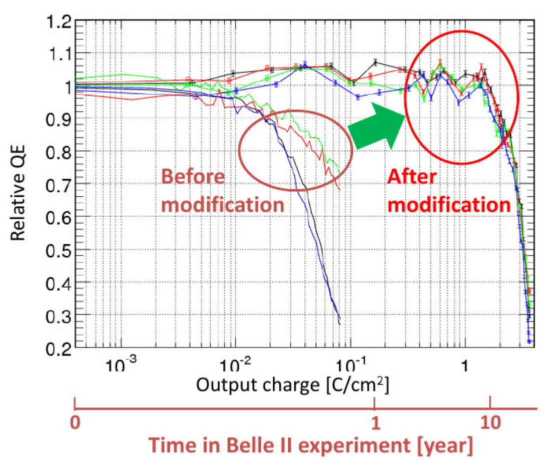


Fig. 6. The lifetime of SL10 before and after the modification.

We have also measured the relative gain and the TTS (Transit Time Spread) as a function of the output charge and the measurements are presented in Fig. 7, where the TTS is measured with the single photon irradiation using the pico-second pulse laser. Though the gains decrease, the TTS is stable.

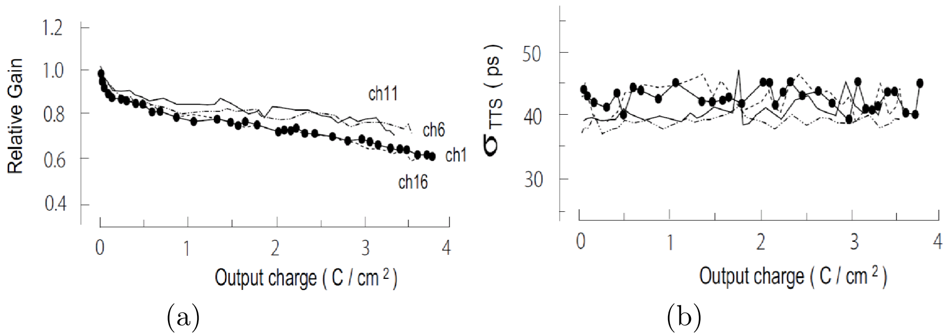


Fig. 7. Relative gain and TTS as the function of the output charge. (a) Relative gain. (b) TTS.

5. Conclusion

We have developed a new PID device — the TOP counter for the upgraded B factory experiment at KEK. It is the square-shape MCP-PMT. It had been already confirmed that the MCP-PMT satisfies the required performances except for the long-range stability — the lifetime. We have demonstrated that the lifetime improves if a modified construction of the MCP-PMT is used. This modification reduces the exposure of the photocathode to the out-gasses. Consequently, the modified square-shape MCP-PMT achieved the lifetime of 2.5 C/cm^2 for 80% of the original quantum efficiency.

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