

Improvement of the MCP-PMT performance under a high count rate

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We developed a square-shaped micro-channel-plate photomultiplier tube (MCP-PMT) for the TOP counter in the Belle II experiment in collaboration with Hamamatsu Photonics K.K. It has a time resolution about 30 ps for single photon detection, a large photocathode of 23 mm square photocathode and a peak quantum efficiency greater than 28% at a wavelength around 360 nm. Those excellent time resolution and efficiency are essential for the TOP counter to reconstruct the Cherenkov image for particle identification. However a major concern of the MCP-PMT is deterioration of the photocathode, and thus drop of the quantum efficiency. That is caused by outgassing from the MCP, of which amount depends on the output charge from the MCP. The quantum efficiency of the initial prototype of the MCP-PMT dropped down to 80% of the beginning at an integrated output charge per photocathode area of only less than 0.1 C/cm^2 . On the other hand, several C/cm^2 is expected for the MCP-PMTs on the TOP counter at 50 ab^{-1} integrated luminosity even when the operation gain of the MCP-PMT is as low as 5×10^5 . That is because the MCP-PMTs suffer from intensive photon hits of several MHz/PMT due to the beam background. Therefore extending the lifetime of the MCP-PMT was absolutely imperative.

We took three steps of approaches to extend the lifetime: blocking the gas and ions from reaching the photocathode by a ceramic cap and an aluminum layer; adopting atomic layer deposition (ALD) technique to coat the MCP surface to prevent outgassing; applying some processes in production to reduce the residual gas on the MCP. By each step, we succeeded in extending the lifetime to about 1 C/cm^2 , about 10 C/cm^2 , and more than 13 C/cm^2 , respectively. The detail of the measurement of the lifetime will also be shown in this presentation.

There is another issue to use the MCP-PMT under such a high count rate: The time resolution of the MCP-PMT becomes worse above several MHz/PMT. The origin of the worse resolution is considered as a local distortion of the electric field in the MCP where the electrons are depleted. The fraction of the depleted region increases as the count rate because it takes $O(10 \text{ ms})$ to recharge the fired micro channels of high resistance by the strip current. This presentation will cover test results of the time resolution under LED backgrounds as well as possible mitigation measures against the deterioration of the time resolution.

Summary

Primary author(s) : MATSUOKA, Kodai (KMI, Nagoya University)

Co-author(s) : HIROSE, Shigeki (Nagoya University); Prof. IJIMA, Toru (KMI, Nagoya University); INAMI, Kenji (Nagoya University); KATO, Yuji (KMI, Nagoya University); KOBAYASHI, Kazuho (Nagoya University); MAEDA, Yosuke (KMI, Nagoya University); MUROYAMA, Genta (Nagoya University); OMORI, Raita (Nagoya University); SUZUKI, Kazuhito (Nagoya University)

Presenter(s) : MATSUOKA, Kodai (KMI, Nagoya University)

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