R&D of MCP-PMTs in XIOPM

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Introduction

Due to its superior temporal resolution, low dark noise and stability in magnetic fields, the Microchannel Plate Photomultiplier Tube (MCP-PMT) is used in particle identification detectors such as PANDA, LHCb and Belle II, as well as for fast neutron or x-ray detection in inertial confinement fusion (ICF) experiments and laser communications.

Since 2011, we have been meticulously studying the properties of the MCP-PMT through simulations and tests, and have created many types of prototypes for nuclear and high-energy physics investigations. Understanding the behavior of these devices and designing better ones is made easier by following the electron process inside the MCP-PMT using 3D simulations.

The Double Cone Ignition (DCI) experiment conducted in China used tens of gated MCP-PMTs with a gating response time of 5 ns and a gating noise amplitude of ±2mV. These MCP-PMTs successfully detected the fast neutron signals in the presence of a strong gamma-ray background. For the detection of strong radiation, a high dynamic range MCP-PMT with a linear output of 250mA@100ns has been developed. We are also developing a long-life, position-sensitive MCP-PMT for the Super Tam Charm Facility (STCF) in China.

Several improvements have been made to make the gated MCP-PMT more robust against interference for neutron measurements.

1). Encapsulate non-sensitive areas of cathode window with light shielding.

2). Reinforced input circuitry and voltage divider circuitry with improved electromagnetic shielding.

3). Application of a triple shield of insulation, anti-magnetism and electrostatic protection to the entire tube body, from internal to external components.

Fig.3 (a) The bare tube; (b) the packaged tube

Fast neutron signals from the DCI laser fusion experiment

The neutron signals acquired under the same experimental conditions in the DCI using a Hamamatsu gated MCP-PMT and a XIOPM gated MCP-PMT at a similar gain. The strong gamma radiation can be shielded with the gating function. The better signal-to-background ratio of the XIOPM gated MCP-PMT is attributed to the larger effective diameter of the photocathode and improved efficiency in collecting the scintillation light.

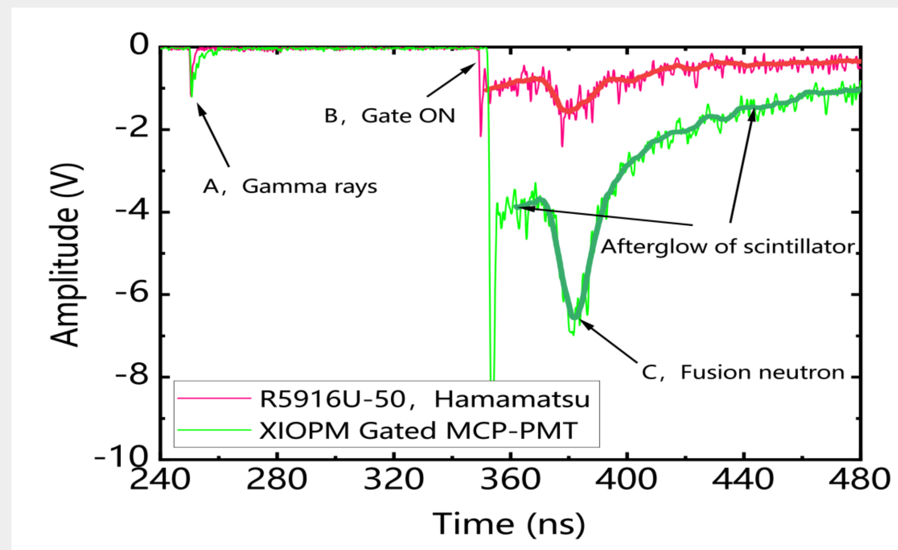


Fig.5 Typical signal obtained from the liquid scintillator neutron time-of-flight detector in the Double Cone Ignition experiment

Gated MCP-PMT

A gated MCP-PMT is created by inserting a gating electrode between the photocathode and the MCP. By modulating the potential difference between the cathode and the gating electrode, the movement of photoelectrons emitted from the cathode can be regulated. The schematic structure is shown in Fig.1 and the simulation results of the gating characteristics are shown in Fig.2.

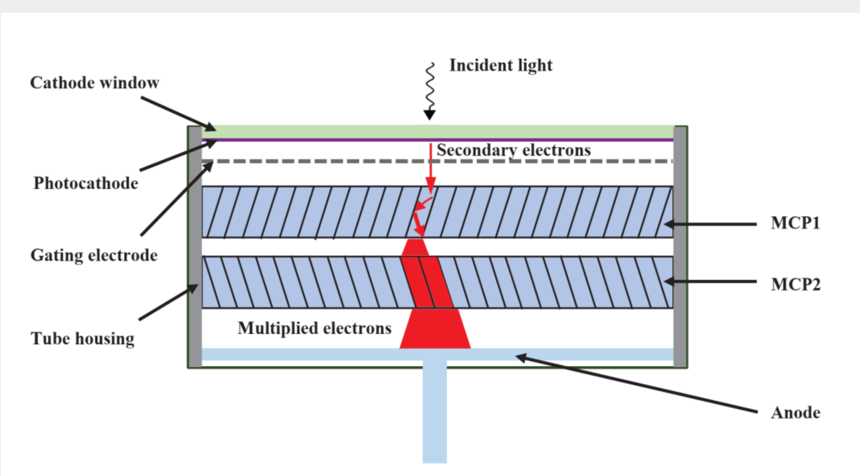


Fig. 1 The schematic structure of the gated MCP-PMT

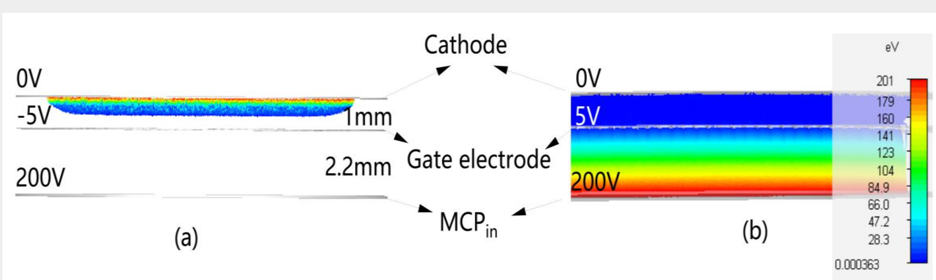


Fig.2 Simulation results of the gating characteristics. ((a)When the potential of the gating electrode is less than the potential of the cathode, it prevents electrons from going to the MCP. (b)When the potential of the gating electrode exceeds that of the cathode, it allows electrons to access the MCP).

Gain

The current gain of the gated MCP-PMT at different input light intensities is shown in Fig. 4. The gain is lower as increasing the light intensity. This is due to the MCP saturation.

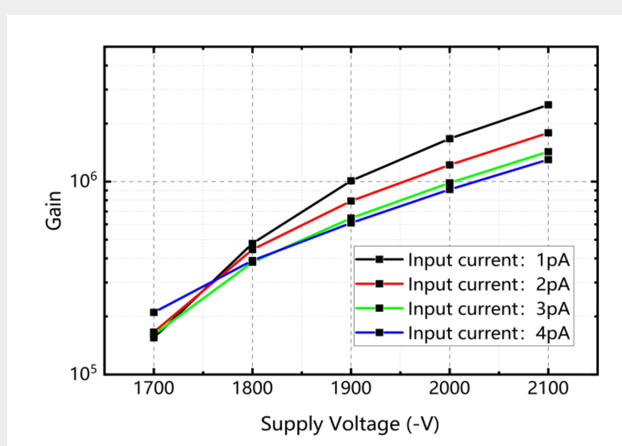


Fig. 4 Gain of the gated MCP-PMT at different input intensity.

Time response

- The rise time of the gated MCP-PMT is less than 350 ps. The FWHM of the time response is less than 700 ps. The TTS is less than 50 ps.
- The gating response time is influenced by the rise time of the gating signal and the speed of propagation of the gating signal on the gating electrode. Gating response time of 5 ns is achieved.

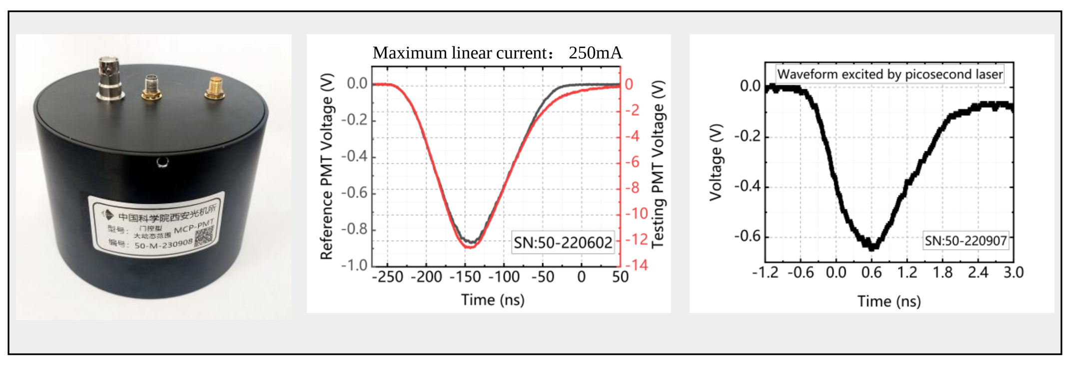
Gating characteristics

- The switching ratio of more than 1000:1 has been achieved with a gain of 1E6 for a 10 ns pulse.
- By adjusting R_{eq} and C_{eq} values, it is possible to achieve a gating width exceeding 2 ms.
- Several strategies have been implemented to reduce gating noise to less than 2 mV.

Large dynamic rage MCP-PMT and multi-anode MCP-PMT

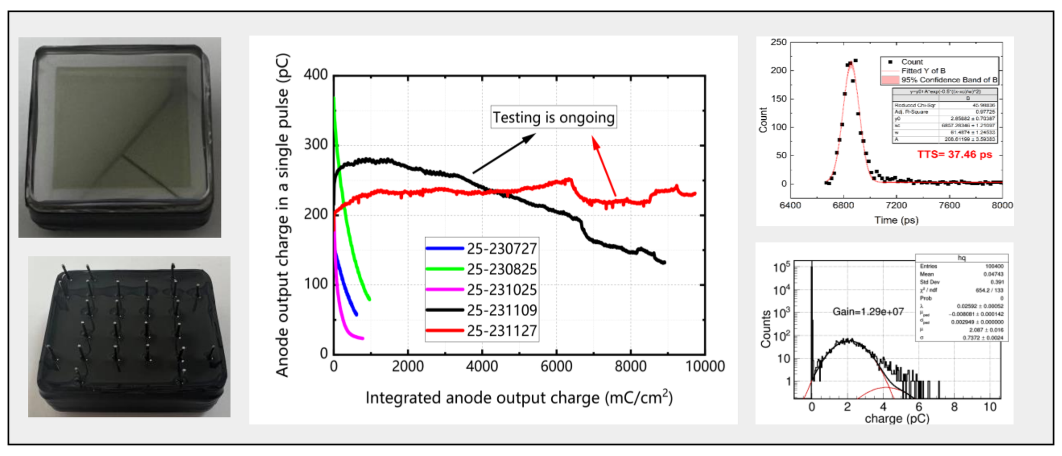
Large dynamic rage MCP-PMT

- Dynamic rage $> 2.5\times10^{8}$ @100ns
- Rising time $<$1ns



Multi-anode MCP-PMT for the STCF

- Life time $>$10C/cm^2 (testing is ongoing)
- T.T.S. $<$40 ps
- Single photoelectron gain $> 1\times10^{7}$



Conclusion

XIOPM has developed several types of MCP-PMTs which are used for fusion neutron detection in the DCI experiment and for particle identification in the DTOF detector of STCF. The high dynamic range gated MCP-PMT can also detect charged particles such as protons and alpha particles with strong gamma radiation, and allows segmented signal measurements with a wide dynamic range.

Acknowledgements

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