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Investigation and development of microchannel plate phototubes ☆

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Abstract

The development of photomultiplier tubes (PMTs) with microchannel plates (MCPs) in Novosibirsk began 10 years ago. PMT based on MCP is compact, has a high time resolution and can work in a strong magnetic field. Eighty such PMTs have been working in ASHIPH counters of the KEDR detector since 2003. Now we are focusing on the MCP PMT lifetime improvement. It was shown that the photocathode lifetime cannot be expressed unambiguously in units of the collected anode charge. Two new models of PMTs were developed: PMT with the photocathode protective layer and PMT with three MCPs. The comparison of the photocathode aging of both new and one old models has been done.

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Keywords: MCP PMT; Photocathode lifetime; Aging effect; Cherenkov counters

1. Introduction

Nowadays the photomultiplier tubes (PMTs) based on microchannel plates (MCPs) are very attractive for use in particle physics [1]. They are able to work in a strong magnetic field, compact and have high time resolution (TTS $\approx$ 35 ps) [2]. MCP allows one to obtain good photon position sensitivity using multianode design of PMT [3].

Works on such PMTs in Novosibirsk began about 10 years ago [4]. Budker Institute of Nuclear Physics and "Katod" enterprise have developed a phototube with two MCPs and a multialkali photocathode. These PMTs are used in ASHIPH counters of the KEDR detector [5,6] at the VEPP-4M e^+e^--collider. The counters have the size of about $50 \times 20 \times 7\,\mathrm{cm}^3$ and are able to work in the magnetic field of up to 1.8 T. The light collection is performed by means of wavelength shifters. Such approach allows us to use only one small PMT per counter.

Eighty counters installed into the KEDR detector have been working in the experiment since 2003.

2. MCP PMT for ASHIPH counters of the KEDR detector

The scheme of PMT used in ASHIPH counters is shown in Fig. 1. PMT has borosilicate window and multialkali photocathode of 18 mm diameter. Spectral response ranges from 360 to 850 nm and has maximum at wavelength of 500 nm [5,6]. The typical quantum efficiency at maximum is 23%.

Two MCPs with 8 μm channel diameter provide the gain 10^6. In axial magnetic field of 2 T the gain drops by 3–5 times [6,7].

The main part of intrinsic noise is determined by thermoelectronic emission from the photocathode. The dark counting rate does not exceed 10^5 cps [7].

The photoelectron collection efficiency is determined by the MCP open area ratio and is 0.6 on average.

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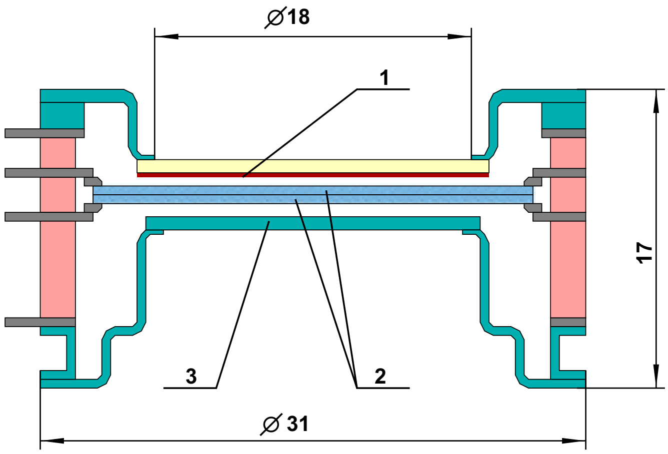

Fig. 1. The MCP PMT layout. 1—photocathode, 2—MCPs, 3—anode. Sizes are in millimeters.

Additional details about parameters of the Novosibirsk MCP PMTs can be found in Refs. [6–8].

3. Operational lifetime of MCP PMTs

The main disadvantage of MCP PMT is a short lifetime of the photocathode. Quantum efficiency degradation is resulted from the bombardment of photocathode by ions.

We performed the measurement of the photocathode lifetime while PMT operated without external illumination. This regime is close to the working condition of PMTs in ASHIPH counters of the KEDR detector. After one year of the operation, we did not observe any changes in quantum efficiency [9]. But under external illumination corresponding to counting rate of $10^6\,s^{-1}$ a rapid decrease of the photocathode sensitivity is observed [7]. This indicates that speed of the photocathode aging depends on PMT operation mode. The lifetime of MCP PMT cannot be expressed unambiguously in the units of the collected anode charge [7].

Also we have found that photocathode degrades much faster in red region of the spectrum (Fig. 2).

4. MCP PMT with a longer lifetime

Low photocathode lifetime under high photon counting rate limits a wide application of the MCP PMT in high energy physics experiments. A sudden short-term rise of a background during an experiment can quickly damage photocathode. From these considerations we started the development of new MCP PMT designs. Recently two new models of PMT were manufactured and tested.

4.1. MCP PMT with a protective layer

A thin layer of aluminum oxide was placed on the entrance of the first MCP to prevent the bombardment of photocathode by ions. However, this layer decreases the

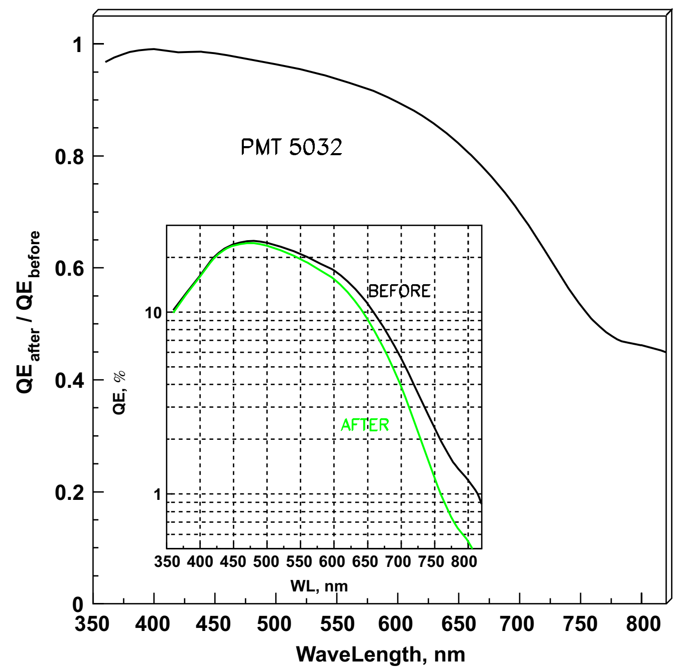

Fig. 2. The dependence of the quantum efficiency degradation on wavelength.

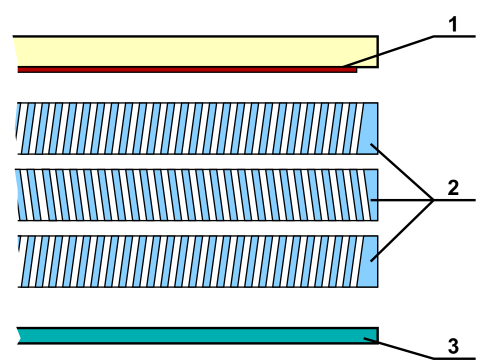

Fig. 3. The scheme of the three MCP PMT. 1—photocathode, 2—MCPs, 3—anode.

photoelectron collection efficiency. We increased the gap between photocathode and the first MCP. That allowed us to apply voltage of 1000 V to the gap and to increase the collection efficiency. Nevertheless the average loss of photoelectrons due to the protective layer is 25% [7].

4.2. PMT with three MCPs

To avoid the loss of collection efficiency we designed PMT with three MCPs without protective layer (Fig. 3).

The third MCP creates an additional barrier for ions the most of which appears near anode. This design does not protect photocathode from ions produced in the first (nearest to photocathode) MCP, but it helps to decrease their number. When PMTs work with the same overall gain the index of electron multiplication of each MCP will be less for PMT with three MCPs than for PMT with two MCPs. Therefore the number of ions produced in the first MCP will be less. The ions flows of both origins are expected to be suppressed.

Additional attractive feature of PMT with three MCPs is its possibility to operate with gain up to 10^8 (Fig. 4).

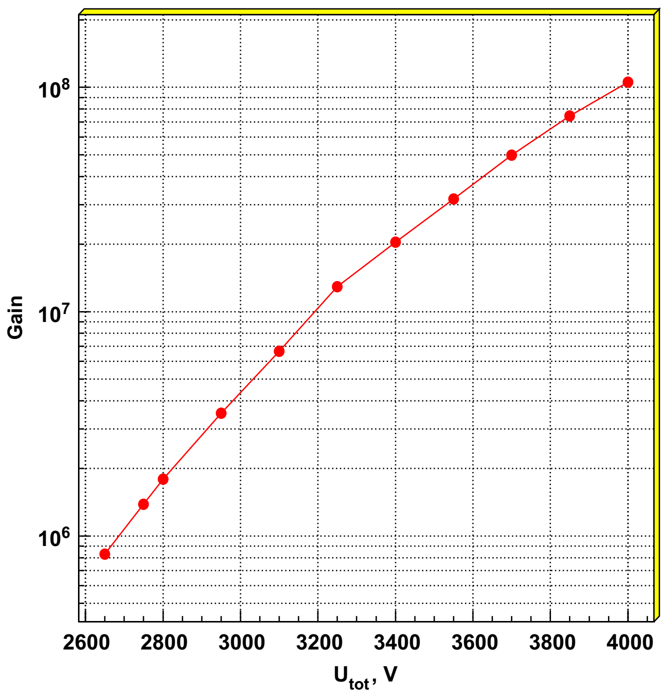

Fig. 4. The dependence of the three MCP PMT gain on voltage.

4.3. Gain in axial magnetic field

The measurements of the gain of the MCP PMTs in an axial magnetic field were done. PMTs of new models as well as PMTs with two MCPs without protective layer were tested. All tested tubes had MCPs with 6 μm channel diameter. Fig. 5 shows the dependence of the gain on the magnetic field strength for PMTs of the new models and PMTs with two MCPs without protective layer. It is seen that PMT with three MCPs is more sensitive to magnetic field. Its gain drops by a factor of 6 in the field of 2 T.

4.4. Comparison of photocathode aging

To compare the aging rate of different models of MCP PMTs we measured degradation of the quantum efficiency after an exposure of the photocathode under different photon counting rate. PMTs operated at a gain of 10^6. Photocathode (its central part with area of 1.8 cm^2) was illuminated by a LED which worked in the pulse regime with a frequency of 100 kHz. We varied the number of photoelectrons per pulse from 10 to 10^3. The duration of exposure was chosen such that collected cathode charge was 5 nC (3×10^{10} electrons) for each value of the counting rate. Fig. 6 shows the dependence of the quantum efficiency change QE_{after}/QE_{before} at wavelength of 800 nm on the photon counting rate for PMTs with two and three MCPs and PMTs with protective layer. It is seen that PMTs of both new models can stand short-term rate up to 10^8 photoelectrons per second while the photocathode of old PMTs greatly degrades at a rate of 10^6 s^{-1}.

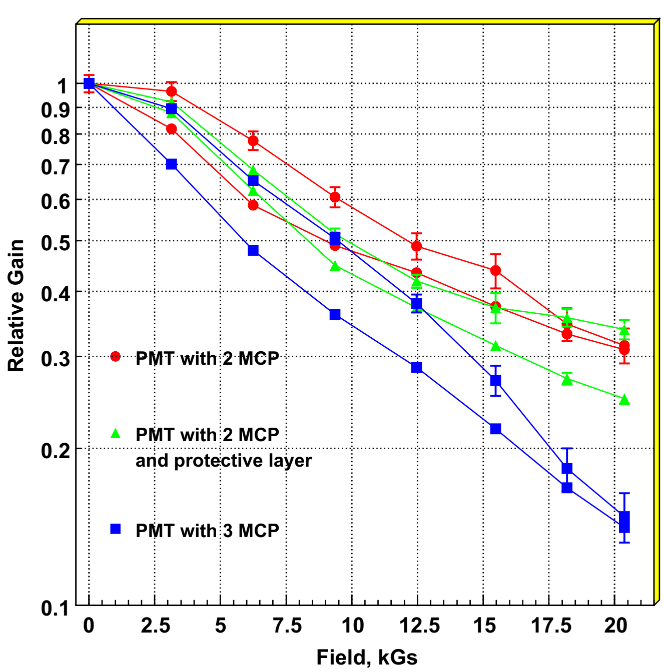

Fig. 5. Magnetic field influence on the gain of the different models of MCP PMTs.

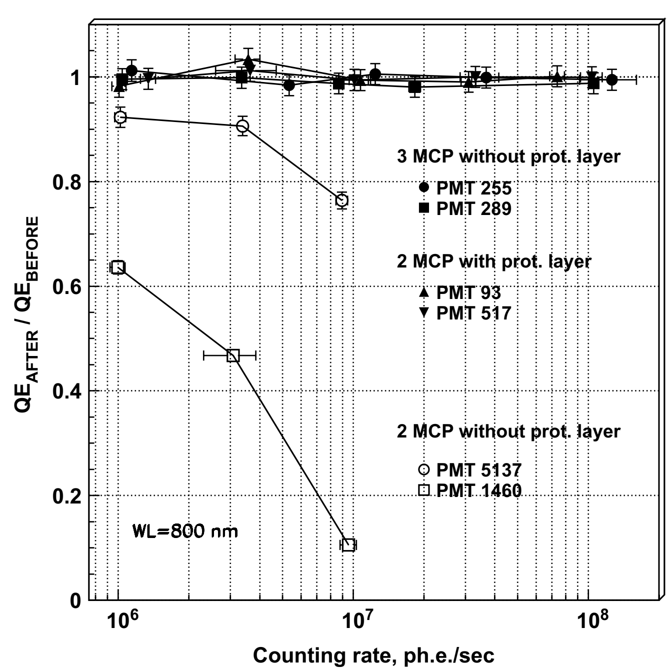

Fig. 6. The dependence of the quantum efficiency change at wavelength of 800 nm on the photon counting rate.

5. Conclusion

For a purpose of the MCP PMT lifetime improvement two models of phototubes were developed:

1. PMT with two MCPs and protective layer,
2. PMT with three MCPs without protective layer.

Comparison of the photocathode aging has shown that both new models of PMT can stand the short-term operation (several minutes) under the photon counting rate up to 10^8 photoelectrons per second. MCP PMTs of new designs look like promising candidates for the application in future experiments of the high energy physics.

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