MCP PMT with high time response and linear output current for neutron time-of-flight detectors

A S Dolotov, P I Konovalov1, R I Nurtdinov
Dukhov Research Institute of Automatics (VNIIA), Sushchevskaya str. 22, Moscow, 127055, Russia

e-mail: p_konovalov@mail.ru

Abstract. A microchannel plate (MCP) photomultiplier tube (PMT) with a subnanosecond time response and a high linear output current has been developed. PMT is designed for detection of weak pulses of radiation in UV-, visible and nearer-IR ranges and can be used in neutron time-of-flight (nTOF) detectors in experiments on laser compression of thermonuclear fuel. The results of measurements of MCP PMT main parameters are presented: photocathode spectral sensitivity, gain, maximum linear output current, and time response.

1. Introduction

In performance of experiments with laser compression of thermonuclear fuel on high-power laser systems, like NIF and OMEGA, the neutron time-of-flight technique is one of the important elements of the system for the plasma nuclear content diagnostics[1, 2]. The main objectives of the technique are to measure the ion temperature of plasma, determine the total neutron yield and the time between the beginning of laser irradiation of a target and the attainment of the maximum neutron yield[3]. The equipment to support the technique at low and medium neutron yields includes detectors based on fast organic scintillators and MCP PMT or a vacuum photocell [3, 4]. The time response of these detectors ranges from 0.2 to 2.5 ns.

This paper deals with VNIIA-developed TNFT25-01 PMT with one MCP and TNFT25-02 PMT with two MCPs that are developed for gamma-ray and neutron detectors to be used in the neutron time-of-flight system. The main peculiarities of these PMTs are narrow FWHM of the output pulse in the linear range of an output current (0.34 ns for PMT with two MCPs and 0.28 ns for PMT with one MCP) at illumination of a photocathode by a light pulse of ~ 0.1 ns, as well as a high linear output current in the pulse mode (more than 1.0 A) at illumination of a photocathode by a light pulse with FWHM of 20 ns.

2. MCP PMT design

MCP PMT vacuum unit comprises an entry window made of quartz glass, on the inner surface of which a 25-mm-diam photocathode is formed. Next to the cathode window, the input surface of a microchannel plate is located. One or two MCPs of MKPO25-8 type manufactured by LLC VTC Baspik to meet specific requirements can be used depending on the necessary gain. Electrons arrive from MCP output at the anode that is connected to a coaxial output with wave resistance 50 Ohm.

MCP PMT vacuum unit is placed in a housing which also incorporates a resistive divider that supplies required potentials to the electrodes. On the end-face of the housing there are 50-Ohm

1 To whom any correspondence should be addressed.
connector of N-type or SMA for recording an output signal, SHV-connector for supplying feed voltage, and a terminal for connecting a grounding wire (figure 1).

Figure 1. MCP PMT outward appearance.

3. MCP PMT main parameters

3.1. Photocathode spectral sensitivity

nTOF detector sensitivity is determined by the properties of the used scintillator, as well as the spectral sensitivity of a photocathode and PMT gain.

Spectral sensitivity of a photocathode of S20UV type was measured in the range of wavelengths from 200 to 800 nm. Figure 2 shows the obtained spectral characteristic in relative units. PMT attains the maximum spectral sensitivity at a wavelength of 370 nm (a typical value ranges from 70 to 90 mA/W). The maximum light yield of BC-422Q fast scintillator used in nTOF detectors corresponds to a wavelength of 370–380 nm, which perfectly matches PMT maximum spectral sensitivity.

Figure 2. Spectral characteristic of MCP PMT with S20UV photocathode.

Figure 3. Gain factor of PMT with two MCPs as a function of MCP voltage.
Figure 3 shows the dependence of a gain factor of PMT with two MCPs on the voltage applied to MCPs. At MCPs’ operating voltages, a gain factor of TNFT25-01 PMT is no less than $5 \times 10^3$, and TNFT25-02 PMT – no less than $1 \times 10^6$. Detectors based on PMTs with such a gain allow measuring the ion temperature at yields from $1 \times 10^9$ to $5 \times 10^{13}$ neutron/pulse [1].

3.2. Maximum linear output current
At high neutron yields the performance of the neutron time-of-flight system is determined by the threshold of PMT saturation. At significant luminous fluxes PMT starts operating in a non-linear mode, which can distort the data on the measured ion temperature. The maximum linear output current in the pulse mode is one of the main PMT parameters, being the value of PMT output current, at which a deviation from the direct proportionality of current to a luminous flux impinging on a photocathode does not exceed the specified value. With respect to the effect on the maximum linear output current of MCP PMT caused by the duration of light emission pulse due to low conductivity of MCP channel walls and large capacitance, the measurement were made for a light pulse with a FWHM of no more than 20 ns.

Figure 4. Measurement results of MCP PMT maximum linear output current.

The measurement method of the maximum linear output current consists in simultaneous recording of the output pulses from PMT and the photodetector while illuminating their photocathodes by a laser pulse. Monitoring of voltage amplitudes is carried out using an oscilloscope incorporated in the anode circuits of PMT and the photodetector. Linearity deviation was determined mathematically.

Figure 4 shows the measurement results of the maximum linear output current in the pulse mode of PMT with two MCPs at illumination of the cathode by a single laser pulse with a FWHM of 6 and 20 ns. It can be seen that at -15% linearity deviation the amplitude of PMT output current attains 3.7 A in the former case and 1.15 A in the latter case.

3.3. Output pulse FWHM and time response
In the ion temperature measurements of plasma using the time-of-flight technique, the time spread $\Delta t$ of neutrons arriving at nTOF detectors is recorded [5]. The measured parameter $\Delta t$ is summed up with the neutron time of flight through scintillation material and with the values of time characteristics of the detector, cables and digitizers used. To minimize measurement errors, the detector time response should be the minimum, and thus, it should be much less than the time spread of neutrons. For scintillator-based detectors these requirements lead to the use of fast MCP PMT with time resolution of a few hundred picoseconds.

For measurement of an output pulse FWHM ($T_{0.5}$) MCP PMT photocathode was completely illuminated by laser pulses of $\sim 0.1$ ns FWHM. The pulses were recorded using an oscilloscope. Figure 5 shows oscillograms of PMT with one MCP and PMT with two MCPs.
The width of a PMT output pulse depends on the time response of a measuring channel, namely, on the width of a light pulse, time response of a recording channel and an oscilloscope. Therefore, own time response $\tau$ of a PMT is calculated from the formula

$$\tau = \sqrt{T_{0.5}^2 - (T_{ch}^2 + T_{osc}^2 + T_r^2)},$$

where $T_{0.5}$ – output pulse FWHM of PMT,
$T_{ch}$ – FWHM of a pulse characteristic of electric signal recording channel,
$T_r$ – radiation pulse FWHM,
$T_{osc}$ – oscilloscope pulse characteristic FWHM.

MCP PMT’s own time response calculated from the formula (1):
- for TNFT25-01 – 0.16 ns at output current of 260 mA;
- for TNFT25-02 – 0.25 ns at output current of 310 mA.

4. Conclusion
Application of original decisions in designing PMT’s individual components allowed VNIIA specialists to create a microchannel plate photomultiplier tube with high time and current characteristics. The obtained results demonstrate that the photomultiplier tube parameters are on a par with those of the best international analogues, and even better in some cases [6, 7]. PMT can be used in nTOF detectors during the experiments on laser compression of thermonuclear fuel.

References

[1] Ali Z A et al 2008 Rev. Sci. Instrum. 79 10E527.
[2] Glebov V Y et al 2010 Rev. Sci. Instrum. 81 10D325.
[3] Lerche R A et al 2010 Rev. Sci. Instrum. 81 10D319.
[4] Stoeckl C et al 2010 Rev. Sci. Instrum. 81 10D302.
[5] Glebov V Y et al 2004 Rev. Sci. Instrum. 75.
[6] Milnes J S and Howorth JR 2005 Proc. SPIE 5580 730–40.
[7] Howorth J R et al 2006 HSPP Conference.