Measurement of Energy Distribution of Output Electrons From a Microchannel Plate Based on Vacuum Photodiode

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ABSTRACT  The energy distribution of output electrons (EDOE) from a microchannel plate (MCP) is measured using electrons emitted by a vacuum photodiode excited by a 266 nm Ti-sapphire femtosecond laser. The photoelectrons emitted from the photocathode are focused on a specific location of the MCP by a magnetic lens. While exist an enough voltage difference between the two ends of MCP, the energy distribution curve of output electrons form MCP can be obtained by analyzing the data as function of the bias voltage applied to the charge collector. The result shows that the energy distribution curve obtained by this means consists of a sharp and a long tail when using pulse light source. The most probable electron energy (MPE) is 12.64 eV and the full width at half maximum (FWHM) of the energy distribution curve is about 29.23 eV while the applied voltage difference is 700 V in the experimental setup. The MPE is 10.63 eV and the FWHM of the energy distribution is 22.436 eV in simulation. The measured curve is consistent with the expectation from simulation.

INDEX TERMS  Measurement, microchannel plate, output electron, energy distribution, vacuum photodiode.

I. INTRODUCTION

Microchannel plate (MCP) as current multiplying optical device plays an important role in image intensifier tubes for imaging and intensification of the photoelectron image [1]. The gain parameters of MCPs have been studied previously [1], [2]. Usually, the MCP is fused by hollow glass fibers whose inside surface is covered by a resistive secondary emission film. When applying an enough voltage difference between the two ends of MCP, the incident primary electron striking on the inside surface of the microchannel produces a number of secondary electrons as output. To better understand the characteristics of the MCP, the MCP is studied from different perspectives, such as the secondary electron emission from the surface of different metals or components [3]–[6] and the energy distribution of output electrons (EDOE) from the MCP [7]–[11].

The information about the EDOE is important for many different applications, especially for the spatial resolution of image devices, photomultiplier tube (PMT) systems and in the field of weak light or particle detection. In previous literatures, the single channel electron multipliers (CEM) were studied and the EDOE from the CEM were studied [13]–[15]. The EDOE from MCP was measured by means of the alternating current retarding-field method [7], [12]. The light source was a direct current (DC) source and the EDOE obtained was broad in energy spread. The pulse light source was not mentioned. The EDOE from MCP was studied in detail by Nobuyoshi Koshida et al. [8], [9]. The EDOE was almost entirely determined by the electric potential distribution along the channel wall in the region near to the output end [9]. The width of the energy distribution curve was found to depend on the applied voltage on the MCP and the length-to-diameter ratio of the channel [8].

In this paper, the pulse light source is used for exploratory investigation and the vacuum photodiode is used to measure...
the EDOE from MCP. The pulse light source not mentioned in previous literatures is now widely used in different fields. The PMT system mainly consists of an electron gun and a photomultiplier device. The standard framing tube is modified by removing the phosphor screen and coupling with a strip line charge collector [16]–[18]. As it is known, the MCP operates under two distinct modes, unsaturated and saturated. Here, the operation of the MCP is unsaturated. The full width at half maximum (FWHM) and the most probable electron energy (MPE) of the energy distribution curve are obtained. The energy distribution curve is found to consist of a sharp main peak and a long tail extending over a wide energy range.

II. DEVICE DESCRIPTION

The whole measuring device shown in Fig.1 (a) consists of a Ti-sapphire femtosecond laser source, a photomultiplier tube system and an oscilloscope with 6 GHz bandwidth (SDA 760Zi-A). The PMT system shown in Fig.1 (b) consists of the photocathode (PC), a ground mesh, a drift tube, magnetic lens, the MCP and a charge collector. The PC, the ground mesh, the MCP and the charge collector are located in a high vacuum chamber during the measurements.

The PC operates in transmission mode and has a microstrip line structure, it is coated with a 80 nm thick layer of Au. The width and length of the microstrip line are 8 mm and 35 mm, respectively. The accelerating gap from the PC to the ground mesh is 1 mm. The ground mesh, made of nickel, is 20 lp/mm and the open area is 60%. The drift distance is about 500 mm from the ground mesh to the input surface of the MCP. The photograph and structural diagram of the MCP are shown in Fig.2 (a) and (b), respectively. In this paper, a straight-channel MCP with an active area of 56 mm in diameter, a channel diameter $d$ of 12 $\mu$m, a length-to-diameter ratio $\alpha$ of 40, a bias angle $\theta$ of 6$^\circ$, and an open area factor $\epsilon$ of 0.6, is used in our research group. Moreover, the input and output surfaces of the MCP are coated with 500 nm Cu overlaid by 100 nm Au. The charge collector with microstrip line structure is fabricated on a printed circuit board (PCB) of 0.5 mm thickness. The width, length, thickness and impedance of the microstrip line are 2 mm, 200 mm, 3 $\mu$m and about 50 $\Omega$, respectively. The distance between the output surface of the MCP and charge collector is about 1 mm. The electrodes of the PC are connected to the outside by HV connector and the charge collector are connected to the outside by vacuum sealed SMA connectors. For the PC, two 470 pF capacitors are connected in the broken taped photocathode electrodes to block DC bias voltage. The magnetic lens consists of a soft iron frame and a 1320-turn copper cathode electrodes, it is placed on the outer surface of the drift tube. The inner diameter, outer diameter and axial length of magnetic lens are 160 mm, 256 mm and 100 mm, respectively. The width of circular slit in the inner cylinder is 4 mm.

In the PMT system, the photoelectrons are emitted from the PC and accelerated by a negative DC high voltage between the PC and the ground mesh. Then, the photoelectrons enter drift region after accelerating. To make sure that electron signal can be collected by the charge collector after having been amplified by MCP, the photoelectrons are focused on a specific location of the input surface of the MCP by applying different bias voltages on the charge collector. Finally, the electron signal of output electrons from the MCP is collected by the charge collector and measured by an oscilloscope with a 6 GHz bandwidth (SDA 760Zi-A LeCroy). The measurements are taken with exactly the same setup and the oscilloscope is triggered by the signal form itself.

III. MEASUREMENT, SETUP AND RESULTS

The experimental measurement setup of the energy distribution of output electrons from the MCP is shown in Fig.3.
We use the Ti-sapphire femtosecond laser as pulse light source. There are two laser beams with wavelengths of the 266 nm and 800 nm emitted from the Ti-sapphire femtosecond laser. The width of the 800 nm laser beam is about 130 fs.

The energy of 266 nm laser pulse is about 35 µJ and the laser spot size on the photocathode is about 2 mm in diameter. The bias voltage of the PC is kept at −3 kV and photoelectrons are emitted from the PC when it is illuminated by the 266 nm laser pulse beam. The current applied to the magnetic lens is 0.397 A and an axially symmetric non-uniform magnetic field is produced. Under the influence of magnetic field, the electrons are accelerated across the drift region and reach the input surface of the MCP. The focusing field is a static magnetic field. The magnetic field is only used for electrons’ focusing and it doesn’t influence the incident energy of electrons. The bias voltages of the input surface and the output surface of the MCP are kept at −700 V and at 0 V respectively. The voltage difference between the photocathode and the input surface of the MCP ensures that the electrons nearly have the same energy when they reach the input surface of the MCP. The electrons are multiplied by the MCP and electron signals of output electrons from MCP obtained from the oscilloscope are shown in Fig.4. The data obtained from the oscilloscope are of good accuracy and can be represented up to the 5th digit. When the applied bias voltage of the charge collector is 0 V, no electric field is produced between the output surface of the MCP and the charge collector. Here we only change the bias voltage of the charge collector within the range 0 V to −800 V with steps of 20 V.

In Fig.4 (a), no retarding field exists when the applied bias voltage of the charge collector is 0 V. The retarding field is produced when the negative bias voltage is applied to the charge collector. The first negative peak and the first positive peak are defined as main pulses. In different measurement curves, a series of similar pulses following the main pulse is considered as ringing noise. The ringing noise is caused by the impedance mismatch between the two vacuum feed through SMA connectors. The first negative pulse signal obtained from the oscilloscope is produced by the output electrons from MCP. When the retarding field exists, the output electrons cannot all reach the collector. Only when the electron energy is higher than the potential energy difference between the MCP output surface and the charge collector the electron can reach the collector. The first positive pulse signal may consist of two parts. One part is the low-energy electrons return to the MCP output surface halfway. Another part is the reflection electrons, the high-energy electrons striking on the charge collector and produce secondary electrons. The produced secondary electrons reflect back to the output surface of the MCP, inducing a positive signal on the charge collector.

In Fig.4, the negative pulse amplitude decreases with the charge collector bias-voltage, because as the retarding field increases, the number of electrons which reach the collector decreases. In Fig.4 (a), the positive pulse amplitude increases with the collector charge bias voltage. When the bias voltage of the collector is low, large number of low-energy electrons return to the MCP output surface halfway. Meanwhile, a few reflection electrons are produced. But in Fig.4 (b), the positive pulse amplitude decreases with the collector charge bias voltage. For these high values of the bias voltage the low-energy electrons don’t get out from the MCP output surface, therefore the electron reflection is strongly suppressed. The positive pulse amplitude increases within a certain range of the collector charge bias voltage and then decreases with the collector charge bias voltage. This demonstrates that the output electrons from the MCP are mainly low energy electrons. Comparing the coordinates of the first negative peaks of different curves in Fig.4 (b), the x-coordinate decreases with the collector charge bias voltage.

We use the Origin to process the data obtained from the oscilloscope [19]. The case of 0 V bias voltage is shown in Fig.5 as an example. The output electrons get out from the MCP at time $t_0$ (point a) and they reach the charge collector at time $t_1$ (point b). Because the collected charge is the time integral of the current and the current is the voltage divided
by the resistance, we can get as total charge:

\[ Q_0 = \int_{t_0}^{t_1} I \, dt = \int_{t_0}^{t_1} \frac{U}{R} \, dt = \frac{1}{R} \int_{t_0}^{t_1} U \, dt \]  

(1)

where \( Q_0 \) is the electrons charge while the retarding voltage is 0 V. \( R \) is the constant value external resistance. \( U \) is the value of the voltage. Then, the number of electrons (\( N_0 \)) with energy greater than 0 eV is estimated as:

\[ N_0 = \frac{Q_0}{e} \]  

(2)

where the \( N_0 \) subscript indicates the retarding voltage and \( e \) is the unit electron charge. Similarly, we can get the values \( N_{-20}, N_{-40}, N_{-60}, \ldots \), and \( N_{-800}, N_0 > N_{-20} > N_{-40} > \cdots > N_{-800} \). The number of electrons in each energy range is obtained making the difference of the \( N_x \) numbers, such as the number of electrons in the energy range from 0 eV to 20 eV is \( N_0 - N_{-20} \). The probability to have an electron in the energy range from 0 eV to 20 eV (\( P_{0-20eV} \)) is

\[ P_{0-20eV} = \frac{N_0 - N_{-20}}{N_{total}} \]  

(3)

where the \( N_{total} = N_0 - N_{-800} \) is total number of output electrons and the external resistance \( R \) gets cancel out in the calculation. The value of the electron energy is the MPE when the \( P_x \) is the maximum.

After normalization, the energy distribution curve is shown in Fig.6 (a). Fig.6 (a) is the experimental curve of EDOE from the MCP. The blue discrete points in Fig.6 (a) are obtained from the processed data. The red line in Fig.6 (a) is the fitting curve. The MPE is 12.64 eV and the FWHM of the energy distribution is 29.23 eV. Obviously, the energy distribution curve consists of a sharp main peak and a long tail extending over a wide energy range. Fig.6 (b) is the simulation curve of EDOE from MCP. The single channel MCP is simulated by CST Studio Suite [20]. In simulation, the incident angle of electron is 6° and the energy of the incident electron is 2300 eV. The voltage difference between the single channel MCP is 700 V.

The length-to-diameter ratio of single channel MCP is 40. A particle 2D Monitor is placed at the end of single channel MCP. By this monitor, the energy distribution of electrons can be obtained. The MPE is 10.63 eV and the FWHM of the energy distribution is 22.436 eV. The impinging angle is fixed due to the impinging angular distribution is not simulated. But the impinging angle is not fixed in experimental. This is may the reason for difference between the two curves in Fig 6.

IV. CONCLUSION AND DISCUSSION

The EDOE from MCP has been measured by MCP-PMT system and the Ti-sapphire femtosecond laser has been used as pulse light source instead of DC light source. While the applied voltage difference of MCP is 700 V, the operation mode of MCP is unsaturated. The FWHM of the energy distribution curve and MPE are obtained by this means in this paper. The energy distribution curve is found to consist of a sharp main peak and a long tail extending over a wide energy range. By experimental measurement, the MPE is 12.64 eV and the FWHM of the energy distribution is 29.23 eV. The MPE is 10.63 eV and the FWHM of the energy distribution is 22.436 eV in simulation. The experimental curve is close to the simulation curve. The future work will be focused on the factors affecting the energy spectrum of the outgoing electrons, such as different light sources, incident energy of electrons and the operating conditions of MCP.

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