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Author
Lo, C.C.

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C. C. Lo and Branko Leskovar

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STUDIES OF PROTOTYPE HIGH-GAIN MICROCHANNEL PLATE PHOTOMULTIPLIERS

C. C. Lo and Branko Leskovar

Abstract

The characteristics of new prototype high gain photomultipliers having two microchannel plates in cascade for electron multiplication have been investigated. Measurements are given of the gain, dark current, quantum efficiency, anode pulse linearity, electron transit time, single and multiphoton-electron time spreads, and pulse height resolution of LEP PM137 8/II and PM137 7/I photomultipliers. The gain as a function of transverse magnetic field has been measured and is discussed. Emphasis is put on the determination of optimum photomultiplier operating conditions, particularly with respect to their pulse height resolution capability. Photomultiplier characteristics as a function of input pulse repetition frequency have been also investigated and discussed.

Introduction

It was previously shown that the timing capabilities of photomultipliers, based on high-gain microchannel plates for electron multiplication and proximity focusing are considerably better than those of conventional multipliers. It was also shown that sensitivity of the photomultiplier characteristics to ambient magnetic fields is significantly decreased by such a configuration. The purpose of this paper is to study the characteristics of new prototype high-gain photomultipliers having two microchannel plates in cascade for electron multiplication. The significant feature of the two microchannel plate electron multiplier is that its gain can be made considerably higher, typically between 10^6 and 10^7, than that obtainable with a single microchannel plate where the average multiplier gain of usually less than 10^6 is achieved. By adjusting the operating voltage of each microchannel plate individually, a significantly higher electron resolution has been achieved. The pulse-height resolution capabilities of the photomultiplier are important for the detection and measurement of very low-light-level scintillations in which only a few electrons are produced. The high resolution permits the elimination of almost all singie-electron dark pulses that accompany low-level scintillations. Possible usage is in tritium counting, certain cases of carbon accounting and Cerenkov counter applications.

Based on previous work, further effort has been made to include measurements of such characteristics as: gain, dark current, quantum efficiency, anode pulse amplitude linearity, electron transit time, single and multiphoton-electron time spreads, and pulse height resolution of LEP PM137 8/II and PM137 7/I photomultipliers. These photomultipliers were designed and manufactured by the Laboratoires d’Electronique et de Physique Appliquée at Limeil-Brévannes, near Paris, France.

Both photomultipliers have (D) KClSb photocathodes with useful diameters of 20 mm. Proximity focusing is used for the input and collector stages. Each photomultiplier incorporates two microchannel plates in cascade. The first microchannel plate has a channel diameter and a length-to-diameter ratio of 40 µm, and 80, respectively. The second plate has a channel diameter of 12.5 µm and a length-to-diameter ratio of 40. Since both photomultipliers are experimental prototypes, both an ion pump and a getter are provided to keep high vacuum in the glass envelope. The ion pump current was continuously monitored during the photomultiplier operation since it served to indicate vacuum conditions.

Measurements of the photomultiplier characteristics and optimization of operating conditions were made using the voltage divider shown in Fig. 1. Electrostatic voltmeters were used to monitor the voltages \( V_{p1} \) and \( V_{p2} \) across the microchannel plates. The microchannel plate currents \( I_{p1} \) and \( I_{p2} \) were also continuously monitored. Voltage adjustments across the microchannel plates were made by means of variable resistors \( R_1 \) and \( R_2 \) in the voltage divider. Measuring systems used in photomultiplier studies were based on the systems given in Ref. 3.

Gain and Dark Current Measurements

Both the gain and dark current measurements were made with the system described in Reference 3. All the electrodes except the photocathode were connected together to be used as the collector.

The photomultiplier, operating as a photodiode with 300V across it, was placed in a marked position; the light level was then adjusted to yield a 10 mV peak-to-peak output signal across the 1 megohm input of an oscilloscope. The photomultiplier was reconnected to the voltage divider shown in Fig. 1, and the voltage across the microchannel plate was increased until the output signal was 100 mV peak to peak which corresponds to a gain of 10 at this voltage. The light level was then attenuated with the same voltage across the microchannel plate to give a 10 mV output signal. With the lower light level setting, the microchannel plate voltage was again increased to yield a 100 mV peak-to-peak output signal corresponding to a gain of 100. The same procedure was repeated until the maximum recommended plate voltages were reached. For the PM137 8/II, the gain was 5 x 10^6 with \( V_k=200V \), \( V_{p1}=1700 \), \( I_{p1}=8 \times 10^{-6}A \), \( V_{p2}=700V \), \( I_{p2}=12 \times 10^{-6}A \), and \( V_A=300V \) while the dark current with these voltages was 5 x 10^{-9}A. For the PM137 7/I, the gain was 2.5 x 10^6 with \( V_k=200V \), \( V_{p1}=1600V \), \( I_{p1}=9 \times 10^{-6} \), \( V_{p2}=800 \), \( I_{p2}=5 \times 10^{-7}A \), and \( V_A=300V \) and the dark current 3 x 10^{-9}A. Figure 2 shows the gain and dark current characteristics for both the PM137 8/II and PM137 7/I photomultipliers.

Quantum Efficiency Measurements

A calibrated 8850 with bialkali photocathode was used as the standard for comparison. The photocathode, masked to leave a 2 cm (photocathode diameter of the PM137) diameter area at the center, was placed in a marked position. The light source was adjusted to yield an output signal of 20 mV peak to peak across 1 megohm from the 8850 with 500V between the photocathode and anode. With the same light level setting,
single photoelectron pulse response, was calculated by measuring the output width and amplitude and knowing the gain of the photomultipliers at the microchannel plate operating voltage. Fig. 7 shows the plot of the time resolution as a function of the number of photoelectrons per pulse from one photomultiplier up to 2300 photoelectrons. The time resolution of the single photoelectron pulses was 2.6 ns FWHM indicating the light pulse was very close to 2.6 ns wide; the time resolution tapered down to approximately 45 ps FWHM with 2300 photoelectrons per pulse for the photomultiplier PM137 8/II.

Pulse Height Resolution Measurement

The same system described in Reference 3 was used to make the pulse height resolution measurement. The drive signal applied to the LED was adjusted to yield one, two, three or more photoelectron pulses. With the manufacturer’s recommended operating microchannel plate voltages: i.e., \( V_{\text{p1}} = 1700 \text{V}, V_{\text{p2}} = 700 \text{V} \) for PM137 8/II and \( V_{\text{p1}} = 1600 \text{V}, V_{\text{p2}} = 800 \text{V} \) for PM137 7/1, the first peak to valley ratio of MCP 8/II was 3 to 1 and MCP 7/1 was 1.6 to 1. The dark pulse count for the photomultiplier PM137 8/II when operating at a gain of \( 1 \times 10^6 \) using recommended operating voltage was found to be 16 photoelectron

\[
N = 400 \text{ counts per second}
\]

1/8 photoelectron
For the photomultiplier PM137 7/1 the dark-pulse count was
\[
16 \text{ photoelectron} \sum = 315 \text{ counts per second} \quad 1/8 \text{ photoelectron}
\]

Similar measurements made on a RCA 8850 shows the photomultiplier had dark count rate of 145 pps operating at a gain of 1 x 10^6.

Optimization of Operating Conditions for Best Pulse Height Resolution

Since it is the first microchannel plate which receives photoelectrons from the photocathode, the operating voltage of this plate has the greatest effect on the collection efficiency and the pulse height resolution. As mentioned earlier with the recommended operating voltages, the first peak-to-valley ratio of PM137 8/11 and PM137 7/1 were 3:1 and 1.6:1, respectively, and the maximum resolvable number of peaks was 3. It was decided that the first plate voltage was to be increased to study the changes in the pulse height spectrum of both photomultipliers. As the first plate voltage was raised the dark current increased significantly hence the second plate voltage was lowered to keep the dark current within approximately a factor of two of the original levels. In the case of PM 137 7/1 the optimized values of \(V_{p1}\) and \(V_{p2}\) were 2100V and 540V respectively for the best first peak-to-valley ratio which was 2:1 and a maximum resolvable number of peaks was 4. However, at these voltage settings the PM137 7/1 was observed to put out occasional high amplitude dark pulses indicating possible positive ion feedback. The improvement is not significant enough to warrant any change in operating voltages in this case.

In the case of PM137 8/11, by changing the voltage of \(V_{p1}\) to 2100V and \(V_{p2}\) to 525V, the first peak-to-valley ratio becomes 15:1, and the maximum resolvable number of peaks, 8. At these operating voltages, the overall gain of the photomultiplier is \(2 \times 10^6\) and the dark current is \(12 \times 10^{-9}\)A. The time resolution characteristics of the device remained unchanged. Figure 8 shows a pulse height spectrum of PM137 8/11 under optimized operating conditions for best pulse height resolution. To the authors' knowledge, this is the highest pulse height resolution ever measured on a high-gain fast photomultiplier.

Transverse Magnetic Field Measurement

Data given in Reference 3 shows that the microchannel plate photomultipliers are more sensitive to transverse magnetic fields than axial magnetic fields. At the time of the measurement a magnet large enough to accommodate this device in an axial orientation was not available hence only measurements in a transverse magnetic field were made. The ion pump magnet was removed from the photomultipliers during the entire length of this measurement. The relative gain and collection efficiency of both photomultipliers were measured as a function of magnetic field density. To ensure that the photomultipliers would not be damaged, the highest field applied was restricted to that which did not reduce the response below 20% of the zero field response. As soon as the measurement was completed, the pump magnet was reinstalled and the ion pump turned back on to restore the vacuum of the devices. Figure 9 shows the gain and collection efficiency of PM137 8/11 as a function of the transverse magnetic field density for two directions of the magnetic field. The 50% point in the worst case is 240 Gauss for both gain and collection efficiency. The 50% point under the same conditions for PM137 7/1 is 270 Gauss.

Maximum Operating Frequency Measurement

The maximum operating frequency of a microchannel plate photomultiplier depends on the number of channels, the recovery time of bias current on the used channel, the bias current and the average number of photoelectrons contained in each signal pulse.

A pulsed light emitting diode was used to generate predominately single photoelectron pulses. The output of the PM137 8/11 photomultiplier was connected to an amplifier and discriminator whose output was counted by a frequency counter. By increasing the repetition frequency of the LED the output counting frequency of the photomultiplier was measured. The output pulse frequency is given in Fig. 10 as a function of input light pulse repetition frequency. The point at which the output pulse repetition frequency deviates from the linearity by 5% is defined as the maximum operating frequency of the photomultiplier. At this point a number of microchannels are not active as electron multipliers because of channel recovery time limitations. The maximum operating frequency was 200 KHz for PM137 8/11 and 250 KHz for PM137 7/1 for predominantly single photoelectron pulses. The number of microchannels in the first microchannel plate for both photomultipliers is estimated to be 160 x 10^4. The second microchannel plate has approximately 160 x 10^4 channels.

Conclusions

Characteristics studies of the two microchannel plate cascade photomultipliers show that the device exhibits excellent pulse height resolution and timing capabilities and very low sensitivity to ambient magnetic fields in comparison to the best conventionally designed photomultipliers. The results obtained are shown in Table 1. Our measurements have shown that the photomultiplier operating characteristics can be optimized for high pulse height resolution and gain. Single photoelectron and multi-photon-electron time spread measuring values obtained should be considered as upper limits because of the time resolution capabilities of the measuring system. Pulse height resolution capabilities of photomultipliers having two microchannel plates in cascade for electron multiplication, when operated under optimized conditions, surpass significantly photomultipliers having dynodes with cesium-activated gallium phosphide secondary emitting surfaces. However, during extensive evaluation time both photomultipliers showed a decrease of photocathode quantum efficiency. Both showed a decrease of the microchannel plate gain. Use of high pumping speed getters in combination with a continuously operating ion pump can improve the quantum efficiency and gain stability.

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Fig. 4 Single photoelectron pulses from the PM137 7/1 using a 200 ps light impulse excitation.

Fig. 5 Single photoelectron time spread of the PM137 8/II and PM137 7/1 as a function of the width of the electroluminescent diode current pulse.

Fig. 6 Single photoelectron time spread of the PM137 8/II photomultiplier.

Fig. 7 Multiphoton-electron time resolution as a function of the number of photoelectrons per pulse, measured width is a 2.6 ns light pulse width.
Fig. 8 Pulse-height spectrum, showing peaks corresponding to one, two, and up to light electron peaks for PM137 8/11 photomultiplier.

Fig. 9 Relative DC gain and collection efficiency as a function of transverse magnetic field.

Fig. 10 The single photoelectron output pulse repetition frequency of the PM137 8/11 and PM137 7/1 as a function of the input light pulse repetition frequency.
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