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Microchannel plate electron multiplier calibration using a discrete detector array

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Abstract

The performance of a microchannel plate electron multiplier (MCP) is known to vary with time and exposure to ions, the atmosphere, and other factors. Clearly the recognition of deterioration in experimental work is of great importance. In the present work the performance of an MCP is straightforwardly measured using a detector array integrated on a silicon chip and results presented. The objective of this work is not to accurately quantify the MCP gain distribution but rather to find the distribution shape to enable straightforward monitoring of variations in gain distribution and identification of conditions under which essentially all MCP output pulses are recorded. Thus, isotope ratios of high quality can be measured. This work further demonstrates the versatility of a discrete detector array developed at Aberystwyth. It enables straightforward remote monitoring of the MCP performance and is especially valuable in space-borne experiments. (Int J Mass Spectrom 176 (1998) 161–166) © 1998 Elsevier Science B.V.

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1. Introduction

Microchannel plate electron multipliers (MCPs) form the front end of many focal plane detectors (FPDs) and the performance of MCPs has been the subject of much experimental and theoretical study [1–11]. In particular the gain distribution and its variation with age and usage are of great interest to MCP users. The objective of the present work is not to accurately quantify the MCP gain distribution but to show:

(a) that variations in the MCP gain distribution can be rapidly and conveniently monitored using a discrete detector array;
(b) the conditions under which essentially all MCP output pulses are measured can be easily identified. This is of great importance in isotope ratio measurements.

Experiments were carried out in which a low current of Kr^+ ions was measured using the Aberystwyth discrete detector array in the focal plane of a miniature mass spectrometer developed at the Jet Propulsion Laboratory intended for space-borne research. The array has been described previously [12–14]. Details of the miniature mass spectrometer are to be published. Each ion is measured by first amplifying the charge using an MCP and then measuring the MCP electron pulse using the discrete detector array. The low ion current enables the mea-

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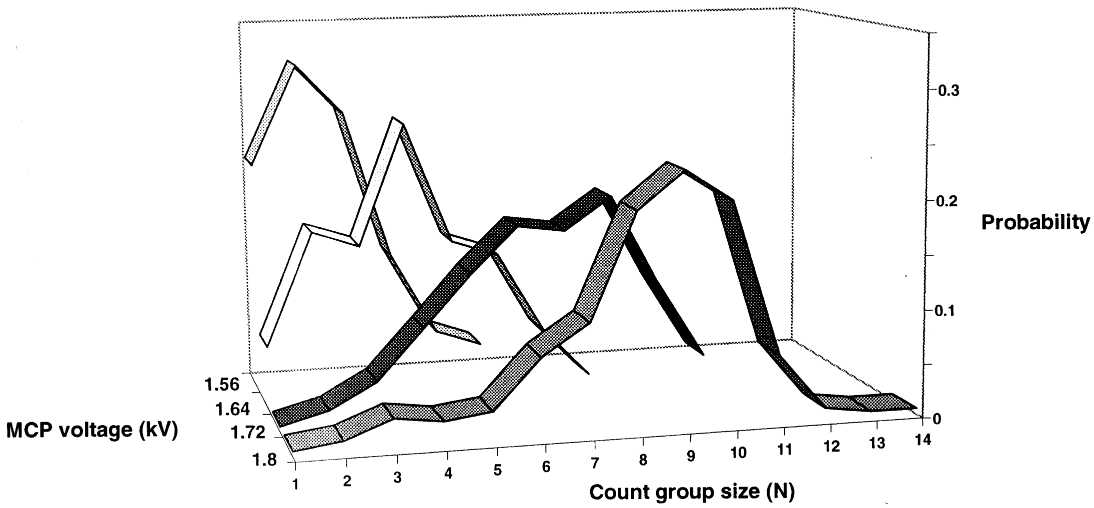

Fig. 1. Count group size distributions plotted for four MCP voltages.

surement and analysis of single events. Single events carry information not only on the location of the event but also on the gain of the electron pulse, and the latter can be found as shown below by combining simulations and single event measurements. These results are important in the understanding of detector array performance, and the calibration procedure is especially useful as a simple means of monitoring performance in space-borne experiments.

2. Measurement of single events

To measure and analyze single events a low intensity beam (2.5×10^{-17} A) of Kr^+ ions was measured for 1 ms and then the array was read and cleared. By repetition of the measurements many single events can be recorded. Each event initiates a single count on N detectors in the vicinity of the event, where $N = 0, 1, 2 \ldots N$ and is known as the count group size (CGS) [15]. For a given physical configuration (e.g. number of MCPs in a stack, separation between MCP exit and array) and electrical configuration (e.g. MCP supply voltage, field between MCP exit and array) of the FPD, the distribution of N depends on the MCP pulse gain distribution. A greater pulse gain gives a greater N because the electron charge falling on detectors remote from the pulse center is greater. In addition to this linear increase of charge falling on remote detectors with increased gain there is greater spreading of a high gain pulse because of space charge repulsion [14]. Therefore, the probability distribution of N gives a measure of the MCP gain distribution. These measurements may be rapidly taken at any time during an experiment and can be made over the whole or any section of the MCP.

Fig. 1 shows CGS distributions measured over a range of MCP voltages under the conditions shown in Table 1. Each distribution took 1 s to measure. The exact correspondence between the distribution of N and the distribution of MCP pulse gain depends on the

Table 1
FPD specification and experimental conditions[a]

MCP—chevron arrangement of 2 Hamamatsu MCPs in intimate contact	channel diameter = 12 μm channel pitch = 15 μm
MCP/array interface	MCP/array bias = 50 V MCP/array separation about 200 μm
Ion current	2.5×10^{-17} A
Measurement period	1 ms
No. of scans	1000

[a] The Aberystwyth array containing 192 detectors on a pitch of 25 μm was used.

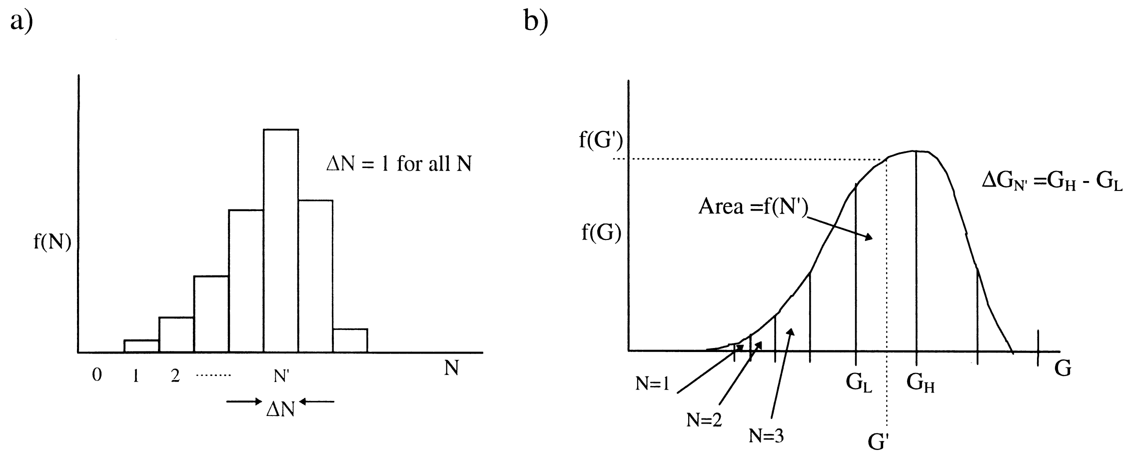

Fig. 2. (a) Measured count group size distribution. (b) MCP pulse gain distribution. MCP pulses between G_L and G_H give count groups of size N'.

configuration of the FPD but the qualitative similarity between the distributions of Fig. 1 and the MCP gain distribution [16] is evident. At a low MCP voltage there is a quasiexponential gain decrease, shifting to a peaked distribution at higher MCP voltages.

2.1. Calculation of MCP pulse gain distributions

Fig. 2(a) shows a schematic of a count group size distribution [$f(N)$] and its relationship with the MCP gain distribution [$f(G)$] is indicated [Fig. 2(b)]. The gain distribution is divided into segments and MCP pulses in a given segment give count groups of a given size. Therefore, using the nomenclature in Fig. 2 and assuming $f(N)$ and $f(G)$ are both normalized we have:

$$f(N') \approx \int_{G_L}^{G_H} f(G) \cdot dG$$

$$\approx f(G') \cdot \Delta G_{N'}$$

$$\therefore f(G') \approx \frac{f(N')}{\Delta G_{N'}}$$

Therefore, the MCP gain distribution can be calculated by measuring $f(N)$ and dividing by the corresponding ΔG_N. The latter was found using a simulator described previously [15]. A plot of $f(G_N)$ versus G_N (the midpoint of ΔG_N) gives a reasonable approximation of the gain distribution.

2.2. Simulated count group sizes

Simulations were carried out in which count group size was found as a function of gain for the given conditions. Present simulations differed from those previously reported [15] in that a simpler form of the electron pulse profile falling on the FPD (a truncated cone) was used, as shown in Fig. 3. This is a close approximation to the profile previously used and enabled computations to be carried out more rapidly.

The simulation data are shown in Fig. 4 and Table 2 and were obtained by setting all simulator parameters to match the best estimates of the experimental conditions (shown in Table 1). The MCP pulse gain was varied in small steps of 5×10^4 and the CGS calculated at each gain. Thus, the value of ΔG_N and

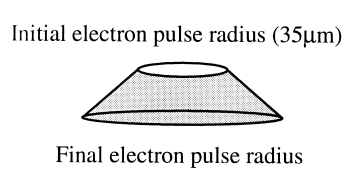

Fig. 3. Intensity profile of electrons falling on the detector array.

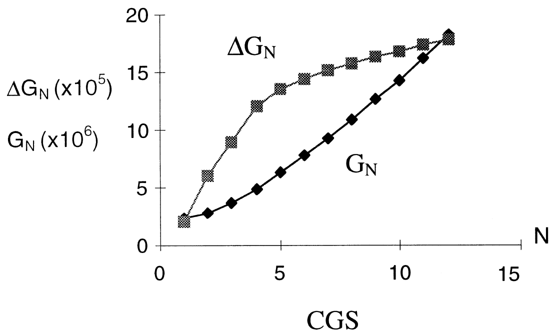

Fig. 4. Simulation results showing the range of gains (ΔG_N, upper curve) over which N detectors are activated and the mid (G_N) point of each range.

G_N (the midpoint of ΔG_N) can be read. The initial MCP pulse radius (Fig. 3) was 35 μm and the final radius was calculated by the simulator. The initial radius was in line with the value found previously [15]. The results can be understood as follows. At the MCP exit the radius of the emerging electron pulse is about 35 μm. The pulse spreads on traveling to the detector array and high gain pulses can activate detectors up to about six detectors from the pulse center (giving count groups with $N \approx 12$). Low gain pulses on the other hand will not spread so much because there is less space charge repulsion. The radius of the pulse on reaching the detector array cannot be less than the radius at the MCP exit and as the MCP pulse gain becomes lower the final pulse radius becomes approximately constant. When the gain approaches the lower detector limit the electric charge falling on the three or four detectors immediately beneath the pulse center tends to decrease together giving a narrower gain range for $N = 4, 3, 2$, and 1.

From the simulator results, the ΔG_N and the G_N can both be plotted against the count group size as shown in Fig. 4, and the count group size distribution can be simply converted to a MCP pulse distribution as shown in Sec. 2.1.

Table 2
Simulation data

N	ΔG_N ($\times 10^6$)	G_N ($\times 10^6$)
1	0.30	2.4
2	0.71	2.8
3	1.00	3.7
4	1.20	4.9
5	1.35	6.3
6	1.44	7.8
7	1.51	9.2
8	1.57	10.9
9	1.63	12.6
10	1.68	14.3
11	1.73	16.2
12	1.78	18.3

2.3. MCP pulse gain distribution

If ΔG_N is constant then $f(G')$ is proportional to $f(N')$. At high MCP voltages very few events gave small pulse group sizes and because ΔG_N does not vary greatly with N at high N the count group size distribution is very similar in appearance to the MCP gain distribution [Fig. 5(a) and (b)]. There is a much stronger effect at low N because ΔG_N varies strongly with N. Fig. 5(c) and (d) show the CGS distribution and calculated MCP gain distribution at 1.56 kV.

New MCPs were used for these experiments, and the calculated gain distributions were expected to show a high modal gain. At 1.8 kV the quoted gain [11] was 4×10^6 for the two stage MCP used here and the calculated value of the modal gain was about 13×10^6. At 1.56 kV the quoted gain is about 1×10^6.

The main sources of error were as follows:

1. Initial MCP pulse radius ±25%
2. Profile of the MCP pulse on reaching the detectors
3. Detector electrode capacitance ±50%
4. Separation between MCP and array ±50%
5. MCP supply voltage ±5%
6. Error on the quoted MCP gain (not given in the manufacturer's datasheet)

The first four items listed are difficult to measure accurately and although the calculated gain (Fig. 5(b) and 5(d)) was large, it was within the limits of error and does not affect the observation of the changing character of the gain distribution with MCP voltage. It also would not affect the observations of *relative* performance with age or usage.

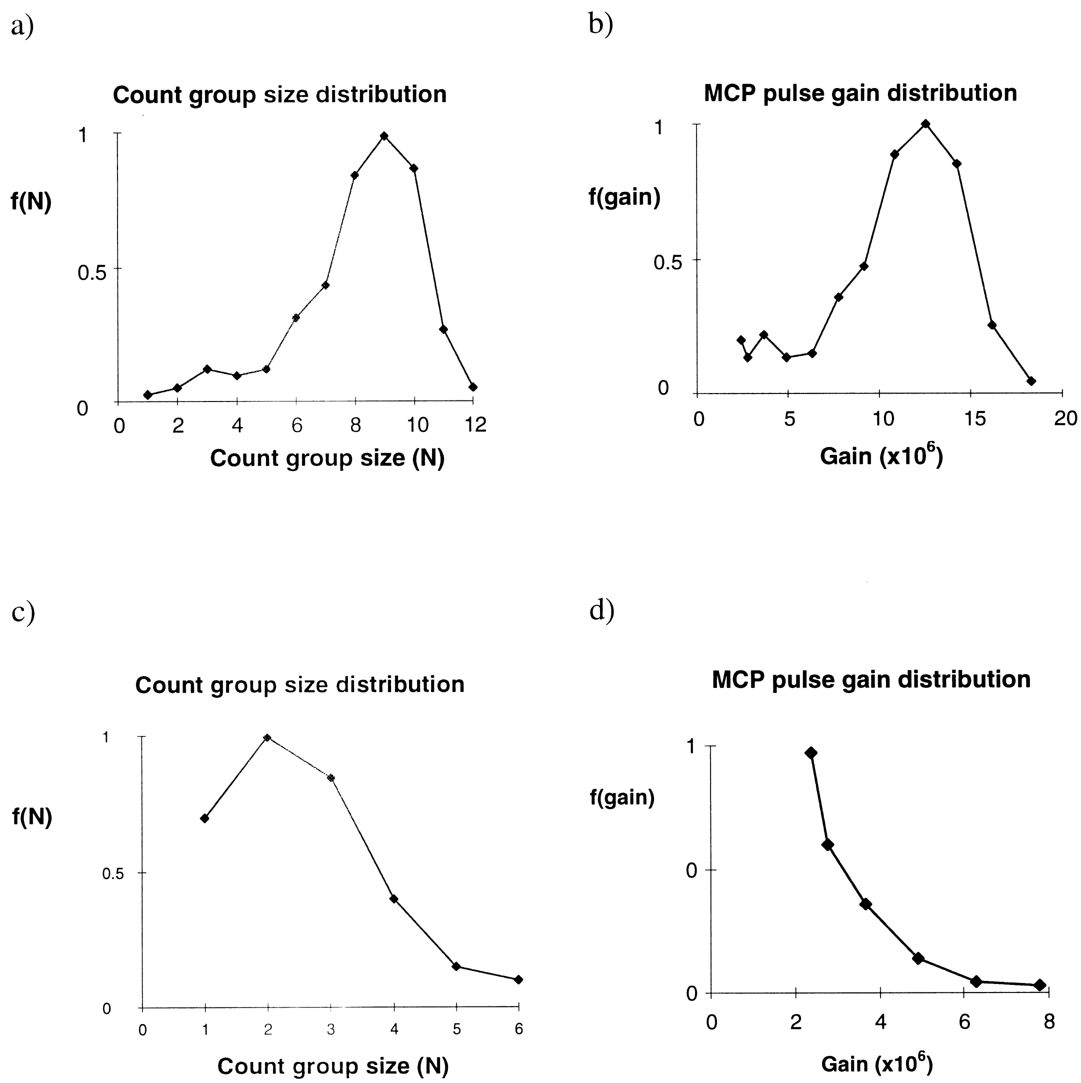

Fig. 5. Experimental count group size distributions and calculated MCP pulse gain distributions. (a) and (b) Results at 1.8 kV; (c) and (d) results at 1.56 kV.

A glance at the count group size distributions of Fig. 1 indicates that at an MCP voltage of 1.8 kV essentially *all* incident ions that activate the MCP are counted because there is no reason to expect a peak in the distribution at $N = 0$. In addition, the resolving power in single event (speckle) mode detection is high [17] and the peak position is known to about ± 2.5 μm. Therefore, the measured spectrum is insensitive to nonuniformity of detector sensitivity using the speckle mode.

2.3.1. Unrecorded events

Fig. 6 shows the total number of events measured at various MCP voltages. At the highest voltages used essentially all events were measured, and because the incident spectrum was unchanged at all MCP voltages

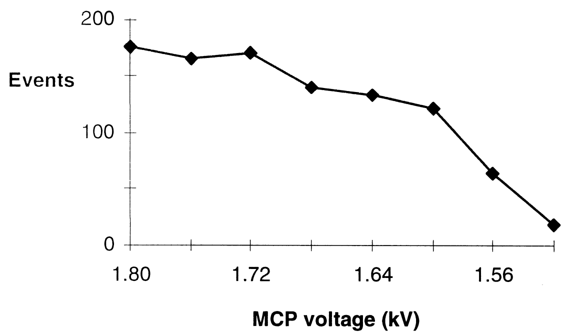

Fig. 6. Variation of the total number of events measured with MCP voltage. The incident ion flux was the same at all MCP voltages and hence the decay shows the increasing number of events giving insufficient gain to be detected.

used, the decrease in the number of measured events at low voltages gives the number of events with insufficient gain to be measured.

3. Conclusions

By detection and analysis of single events using a discrete detector FPD it has been shown that the performance of an MCP can be very simply and rapidly measured. The accuracy of the measurements depends on an accurate knowledge of the FPD setup but *changes* of the gain distribution e.g. with time or usage could be easily monitored.

In the present experiments it is clear from the count group size distributions that at an MCP supply voltage above about 1.7 kV essentially all ions that activate the MCP are counted. Given this and the high resolving power achieved in single event mode operation the measured spectra are of high quality and are insensitive to detector uniformity. This is particularly important in isotope ratio measurements.

Acknowledgements

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