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Resolving power enhancement of a discrete detector (array) by single event detection

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Abstract

Experiments have been performed to demonstrate the high resolving power of a discrete detector array that can be achieved by measuring and processing single ion events (speckle mode). Measurement of the spectrum of Kr^+ using a miniature mass spectrometer developed at the jet propulsion laboratory equipped with a focal plane detector developed at Aberystwyth show a large resolving power enhancement in the speckle mode and good agreement with tabulated peak centroids and isotope abundances. The mode of operation of the instrument is under software control and is instantly variable. This clearly demonstrates the versatility and high performance of the miniaturised system. (Int J Mass Spectrom 176 (1998) 99–102) © 1998 Elsevier Science B.V.

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1. Introduction

A miniature mass spectrometer has been developed at the jet propulsion laboratory (JPL) for space-borne experiments and includes a very small and low power focal plane detector (FPD). Details of the mass spectrometer are to be published. The FPD was developed at Aberystwyth and has been described previously [1–3] (FPD refers to the combination of a microchannel plate electron multiplier [MCP] and the detector array). Its performance has been the subject of a number of publications [1–3]. This paper concerns the resolving power of the FPD.

An ion is measured using the FPD by first amplifying the ionic charge using an MCP. A single MCP output pulse falls on the input electrodes of the array of detectors and a single count may be recorded by one or more detectors. Normally a spectrum is measured by accumulating these counts before readout, but by measuring for a shorter period (e.g. 1 ms) and by using a sufficiently low ion flux single events can be measured (speckle measurement). Experiments have demonstrated the greatly improved resolving power that can be achieved by accumulating the center of mass (CofM) of count groups instead of accumulating the counts themselves. This is analogous to single event location by charge division [4], but in the present case single events occurring at several places simultaneously can be observed.

2. Spectrum measurement

A measured ion peak is an accumulation of many single ion events. Each event is seen by the detector array as an electron pulse output by the MCP. Be-

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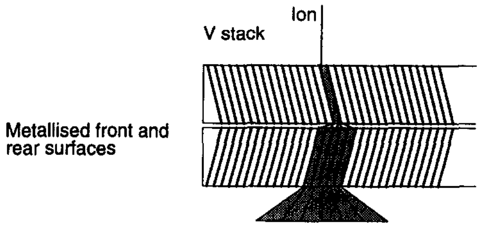

Fig. 1. The electron pulse emitted by the MCP may be wide because of the activation of several MCP channels of the second MCP by one channel of the first and also because of divergence after exit from the MCP.

tween the position of impact of the ion on the MCP and detection by the array there is a spreading of the electron pulse (Fig. 1).

This pulse can initiate a count on more than one detector. The ion spectrum can be measured in two ways:

1. Accumulation mode—the counts generated by the ion events are all added to give the peak. Information on the individual count groups is lost and the measured peak is several detectors wide even if the incident peak is less than one detector wide. The dynamic range is high.
2. Speckle mode—the measurement period is kept low (e.g. 1 ms) and the particle intensity is kept low enough to ensure that within the measurement period mainly single events are recorded. Fig. 2 shows an example of a group of single events. A high resolution spectrum can be generated by recording the CofM of each count group instead of accumulating counts at each detector. The dynamic range in the speckle mode is lower than the accumulation mode.

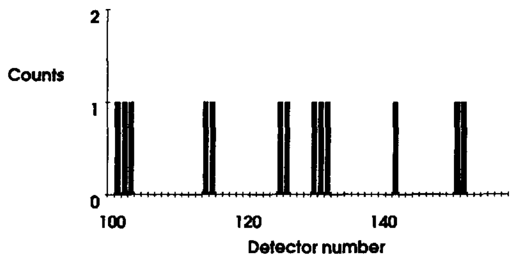

Fig. 2. Single events measured by the FPD. In the present experiments it has been observed that up to 13 detectors can be activated by a single ion.

Table 1
FPD specification and experimental conditions

Array (Aberystwyth array)	192 Detectors (spatial resolution = 25 μm)
MCP—chevron arrangement of 2 Hamamuatsu MCPs in intimate contact	Channel diameter = 12 μm Channel pitch = 15 μm MCP supply voltage = 1700 V
MCP/array interface	MCP/array bias = 50 V MCP/array separation about 150–200 μm
Ion current	2.5×10^{-17} A
Mean count group size	6
Measurement period	1 ms
No. of scans	1000

In the present experiments the relevant experimental parameters are given in Table 1.

3. Kr^+ spectrum

Fig. 3(a) shows the spectrum of Kr^+ measured in the accumulation mode; Fig. 3(b) shows a high resolution spectrum generated from speckle data by accumulating the CofM of count groups (experimental conditions given in Table 1); and Fig. 3(c) shows the spectrum generated from the same speckle data by adding the counts, hence giving a spectrum equivalent to that in Fig. 3(a).

It should be noted that the *y* axis in Fig. 3(b) is labeled "events" because each count group contributes only one to the peak and the sum of events over a peak gives the total measured number of events (Table 2). For a low number of events, the sum over the peaks should be compared in order to calculate the relative concentrations of isotopes. For high event counts, the relative peak heights will give an accurate measure.

The relative peak centroids are accurate to better than 0.01 of a mass unit. This translates to a position accuracy of better than ±2.5 μm. Assuming the Kr gas has the natural isotopic ratios then the measured abundances are within the experimental uncertainty.

A constraint is placed on the maximum ion current

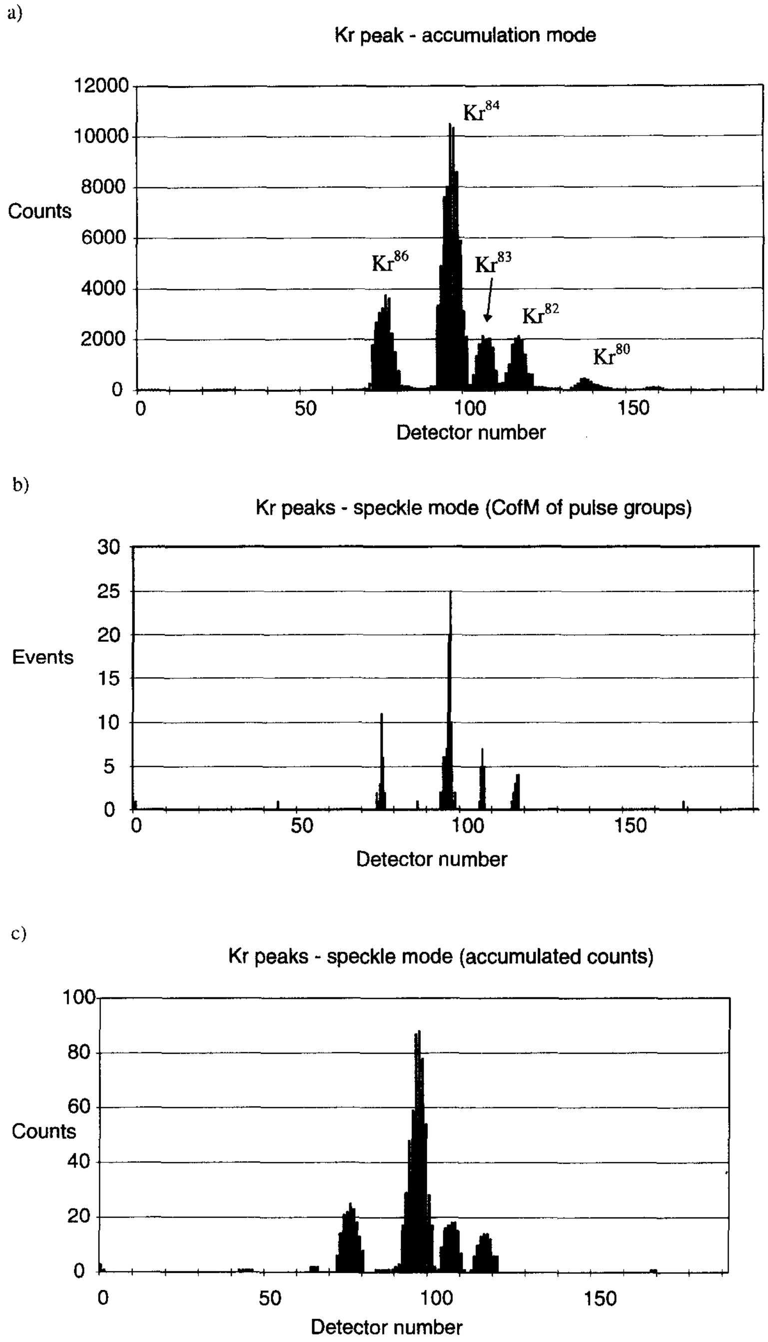

Fig. 3. (a) The spectrum of Kr^+ measured using the normal accumulation mode. The Kr isotopes are identified. (b) Spectrum measured in the speckle mode displaying much narrower peaks. An analysis of these data is tabulated in Table 2. (c) The same raw data as in (b) were processed but counts are accumulated to give a result comparable to (a).

measurable at any one detector in the speckle mode because of the requirement that single events must be observable. For example, if the data accumulation time is 1 ms, an ion flux of 10^3 Hz on one detector would give an average of 1 count per measurement period at that detector but also a significant fraction of

Table 2
Tabulated and measured characteristics of the Kr^+ spectrum shown in Fig. 3(b)[a]

Tabulated values			Measured			
Mass	ΔMass	Abundance (%)	Position	ΔMass (Kr^{86}–Kr^{84} set to 2.00)	No. of events	Abundance (Kr^{84} = 57.0)
79.916		2.25			0	0
	1.997					
81.913		11.6	117.29		14	10.1
	1.001			*1.01*		
82.914		11.5	106.94		18	13.0
	0.997			*1.01*		
83.911		57.0	96.51		79	57.0
	2.000			*2.00*		
85.911		17.3	75.98		25	18.0

[a] Of the total of 140 measured count groups, 4 contained a count >1 and were ignored.

double or triple events. An ion flux of 10^2 Hz would ensure that most events observed were single. The latter flux is $\sim 10^{-3}$ times the maximum count rate allowed by the MCP [3]. Higher ion currents can be measured if the measurement period is reduced but then the data readout time is a greater fraction of the total measurement cycle. Currently the readout time for 192 detectors is $<10^{-4}$ s.

4. Conclusions

The spectrum of Kr^+ has been measured, and it has been shown that a substantial reduction of measured peak width can be achieved by measuring single ion events and accumulating the CofM of count groups instead of accumulating the counts themselves. The mode of operation of the FPD used in this work can be switched simply (under software control) between the high resolution mode and the lower resolution mode. Further study of the speckle measurements will be carried out with the objective of maximising the dynamic range and analysing the influence of nonuniformity.

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