

## MASS SPECTROMETER

## BACKGROUND OF THE INVENTION

The present invention relates to mass spectrometers.

Time of flight mass analysers are discontinuous devices in that they receive a packet of ions which is then injected into the drift region of the time of flight mass analyser by energising a pusher/puller electrode. Once injected into the drift regions, the ions become temporally separated according to their mass to charge ratio and the time taken for an ion to reach a detector can be used to give an accurate determination of the mass to charge ratio of the ion in question.

Many commonly used ion sources are continuous ion sources such as Electrospray or Atmospheric Pressure Chemical Ionisation ("APCI"). In order to couple a continuous ion source to a discontinuous time of flight mass analyser an ion trap may be used. The ion trap may continuously accumulate ions from the ion source and periodically release ions in a pulsed manner so as to ensure a high duty cycle when coupled to a time of flight mass analyser.

A commonly used ion trap is a 3D quadrupole ion trap. 3D quadrupole ion traps comprise a central doughnut shaped electrode together with two generally concave endcap electrodes with hyperbolic surfaces. 3D quadrupole ion traps are relatively small devices and the internal diameter of the central doughnut shaped electrode may be less than 1 cm with the two generally concave endcap electrodes being spaced by a similar amount. Once appropriate confining electric fields have been applied to the ion trap, then the ion containment volume (and hence the number of ions which may be trapped) is relatively small. The maximum density of ions which can be confined in a particular volume is limited by space charge effects since at high densities ions begin to electrostatically repel one another.

It is desired to provide an improved ion trap, particularly one which is suitable for use with a time of flight mass analyser.

## SUMMARY OF THE INVENTION

According to a first aspect of the present invention, there is provided a mass spectrometer comprising:

an ion tunnel ion trap comprising a plurality of electrodes having apertures through which ions are transmitted in use; and

a time of flight mass analyser.

In all embodiments of the present invention ions are not substantially fragmented within the ion tunnel ion trap i.e. the ion tunnel ion trap is not used as a fragmentation cell. Furthermore, an ion tunnel ion trap should not be construed as covering either a linear 2D rod set ion trap or a 3D quadrupole ion trap. An ion tunnel ion trap is different from other forms of ion optical devices such as multipole rod set ion guides because the electrodes forming the main body of the ion trap comprise ring, annular, plate or substantially closed loop electrodes. Ions therefore travel within an aperture within the electrode which is not the case with multipole rod set ion guides.

The ion tunnel ion trap is advantageous compared with a 3D quadrupole ion trap since it may have a much larger ion confinement volume. For example, the ion confinement volume of the ion tunnel ion trap may be selected from the group consisting: (i)  $\geq 20 \text{ mm}^3$ ; (ii)  $\geq 50 \text{ mm}^3$ ; (iii)  $\geq 100 \text{ mm}^3$ ; (iv)  $\geq 200 \text{ mm}^3$ ; (v)  $\geq 500 \text{ mm}^3$ ; (vi)  $\geq 1000 \text{ mm}^3$ ; (vii)  $\geq 1500 \text{ mm}^3$ ; (viii)  $\geq 2000 \text{ mm}^3$ ; (ix)  $\geq 2500 \text{ mm}^3$ ; (x)

$\geq 3000 \text{ mm}^3$ ; and (xi)  $\geq 3500 \text{ mm}^3$ . The increase in the volume available for ion storage may be at least a factor  $\times 2$ ,  $\times 3$ ,  $\times 4$ ,  $\times 5$ ,  $\times 6$ ,  $\times 7$ ,  $\times 8$ ,  $\times 9$ ,  $\times 10$ , or more than  $\times 10$  compared with a conventional 3D quadrupole ion trap.

The time of flight analyser comprises a pusher and/or puller electrode for ejecting packets of ions into a substantially field free or drift region wherein ions contained in a packet of ions are temporally separated according to their mass to charge ratio. Ions are preferably arranged to be released from the ion tunnel ion trap at a predetermined time before or at substantially the same time that the pusher and/or puller electrode ejects a packet of ions into the field free or drift region.

Most if not all of the electrodes forming the ion tunnel ion trap are connected to an AC or RF voltage supply which acts to confine ions with the ion tunnel ion trap. According to less preferred embodiments, the voltage supply may not necessarily output a sinusoidal waveform, and according to some embodiments a non-sinusoidal waveform such as a square wave may be provided.

The ion tunnel ion trap is arranged to accumulate and periodically release ions without substantially fragmenting ions. According to a particularly preferred embodiment, an axial DC voltage gradient may be maintained in use along at least a portion of the length of the ion tunnel ion trap. An axial DC voltage gradient may be particularly beneficial in that it can be arranged so as to urge ions within the ion trap towards the downstream exit region of the ion trap. When the trapping potential at the exit of the ion trap is then removed, ions are urged out of the ion tunnel ion trap by the axial DC voltage gradient. This represents a significant improvement over other forms of ion traps which do not have axial DC voltage gradients.

Preferably, the axial DC voltage difference maintained along a portion of the ion tunnel ion trap is selected from the group consisting of: (i) 0.1–0.5 V; (ii) 0.5–1.0 V; (iii) 1.0–1.5 V; (iv) 1.5–2.0 V; (v) 2.0–2.5 V; (vi) 2.5–3.0 V; (vii) 3.0–3.5 V; (viii) 3.5–4.0 V; (ix) 4.0–4.5 V; (x) 4.5–5.0 V; (xi) 5.0–5.5 V; (xii) 5.5–6.0 V; (xiii) 6.0–6.5 V; (xiv) 6.5–7.0 V; (xv) 7.0–7.5 V; (xvi) 7.5–8.0 V; (xvii) 8.0–8.5 V; (xviii) 8.5–9.0 V; (xix) 9.0–9.5 V; (xx) 9.5–10.0 V; and (xxi)  $>10\text{V}$ . Preferably, an axial DC voltage gradient is maintained along at least a portion of ion tunnel ion trap selected from the group consisting of: (i) 0.01–0.05 V/cm; (ii) 0.05–0.10 V/cm; (iii) 0.10–0.15 V/cm; (iv) 0.15–0.20 V/cm; (v) 0.20–0.25 V/cm; (vi) 0.25–0.30 V/cm; (vii) 0.30–0.35 V/cm; (viii) 0.35–0.40 V/cm; (ix) 0.40–0.45 V/cm; (x) 0.45–0.50 V/cm; (xi) 0.50–0.60 V/cm; (xii) 0.60–0.70 V/cm; (xiii) 0.70–0.80 V/cm; (xiv) 0.80–0.90 V/cm; (xv) 0.90–1.0 V/cm; (xvi) 1.0–1.5 V/cm; (xvii) 1.5–2.0 V/cm; (xviii) 2.0–2.5 V/cm; (xix) 2.5–3.0 V/cm; and (xx)  $>3.0 \text{ V/cm}$ .

In a preferred form, the ion tunnel ion trap comprises a plurality of segments, each segment comprising a plurality of electrodes having apertures through which ions are transmitted and wherein all the electrodes in a segment are maintained at substantially the same DC potential and wherein adjacent electrodes in a segment are supplied with different phases of an AC or RF voltage. A segmented design simplifies the electronics associated with the ion tunnel ion trap.

The ion tunnel ion trap preferably consists of: (i) 10–20 electrodes; (ii) 20–30 electrodes; (iii) 30–40 electrodes; (iv) 40–50 electrodes; (v) 50–60 electrodes; (vi) 60–70 electrodes; (vii) 70–80 electrodes; (viii) 80–90 electrodes; (ix) 90–100 electrodes; (x) 100–110 electrodes; (xi) 110–120 electrodes; (xii) 120–130 electrodes; (xiii) 130–140 elec-