

COAXIAL RING ION TRAP

BACKGROUND

[0001] A mass spectrometer is a device that filters gaseous ions according to their mass-to-charge (m/z) ratio and measures the relative abundance of each ionic species. A typical mass spectrometer comprises an ionization source to generate ions, a mass filter to separate ions in space and/or time, an ion detector to collect filtered ions and measure their relative abundance, a gas supply/vacuum system, and means to power the spectrometer.

[0002] Mass spectrometer performance is generally given in terms of mass range, resolution or resolving power, and sensitivity of the instrument. The mass range regards the lowest and highest masses that can be measured with a particular instrument. For example, a large mass range is desired for the analysis of high molecular weight organic and biological analytes. Resolution (definition of resolution is actual peak shape), or resolving power, regards the ability of the instrument to separate and identify ions of slightly different masses. Sensitivity regards the instrument's response to ions of an arbitrary m/z ratio for a particular sample.

[0003] Recently, there has been a growing interest in the miniaturization of mass spectrometers. The effect of miniaturization on instrument performance depends on the method of mass analysis. For many methods, mass range and resolution often decrease with miniaturization. However, sensitivity may be improved, while power and pumping requirements may be reduced compared to conventional instruments. In general, the smaller dimensions of miniature analyzers reduces the number of collisions that the ion makes with background gases due to the reduced distance of travel. Therefore, operating pressure requirements may be relaxed with miniaturization.

[0004] Mass spectrometers can be classified according to the method by which mass filtering is accomplished using electric and/or magnetic fields. For example, mass filter types can include linear quadrupole, quadrupole ion traps, and cylindrical ion traps, among others.

[0005] Linear quadrupole mass spectrometers (QMS) filter ions by passing them through tuned radio-frequency (rf) and direct current (dc) electrical fields defined by four, symmetrically parallel quadrupole rods. The QMS permits only those ions with a stable trajectory, determined by their m/z ratio, to travel along the entire length of the central axis of the rod assembly without being deflected out of the intra-rod space. Ions with different m/z ratios can be scanned through the QMS by continuously varying the field between the quadrupole rods. Miniature linear quadrupoles require lower drive voltages and higher rf drive frequencies to filter heavier ions and maintain resolution as the electrode dimensions decrease. The relative dimensional and positional precision of the parts must be maintained to provide adequate filtering as their size is reduced.

[0006] A three-dimensional analogue of the linear QMS is the quadrupole ion trap (QIT). Like the linear quadrupole, the QIT can control the stability of ion motion in an electric field and can therefore be used for mass analysis. The QIT comprises a central, donut-shaped hyperboloid ring electrode and two hyperbolic endcap electrodes. In normal usage, the endcaps are held at a static potential, and the rf oscillating drive voltage plus DC offset is applied to the ring electrode. Ion trapping occurs due to the formation of a

trapping potential well in the central intraelectrode region when appropriate time-dependent voltages are applied to the electrodes. The ions orbit in the trap are stabilized or destabilized as the trapping conditions are changed. With mass-selective ejection of ions, the ions become unstable in the Z-direction of the well and are ejected from the trap in order of ascending m/z ratio as the rf voltage or frequency applied to the ring is ramped. The ejected ions can be detected by an external detector, such as an electron multiplier, after passing through an aperture in one of the endcap electrodes. Like the QMS, ion traps have the advantage of being able to operate at higher pressures as a function of smaller size.

[0007] Unlike most other methods of mass analysis, a decrease in the dimensions of the QIT allows trapping of higher m/z ratio ions for fixed operating parameters. Alternatively, for a given m/z ratio, the voltage required to eject ions is reduced quadratically with the linear trap dimension, enabling lower voltages to be used to analyze the same mass range. Like the linear quadrupole, the drive frequency of the QIT must be increased to maintain resolution as the spectrometer dimensions are decreased. A major problem with the miniature ion trap is that the ion storage capacity of the trap decreases with size, reducing the dynamic range and sensitivity.

[0008] A cylindrical ion trap (CIT), comprises planar endcap electrodes and a cylindrical ring electrode instead of hyperbolic electrode surfaces, and produces a field that is approximately quadrupolar near the center of the trap. Therefore, CITs have been found to provide performance comparable to QITs. Moreover, the CIT is favored for miniature ion storage and mass analysis devices because CITs are mechanically simple and can be easily machined. Arrays of miniature CITs, with trap dimensions on the order of a millimeter, have been manufactured using precision machining to regain a portion of the lost storage capacity and thereby improving sensitivity.

[0009] The inner radius of the trapping ring electrode determines the m/z ratio of the trapped ions. Therefore, variable parallel arrays of miniature CITs, each individual trap having a proportionately different size, can be configured to simultaneously trap and monitor different-sized ions. A low-resolution spectra of a multiple ion sample can be obtained from such a variable parallel array by simultaneously ejecting the trapped ions with a dc pulse, without the need to scan the applied rf voltage. The ejected ions can be detected with a position-sensitive detector, resulting in a reduced power requirement and simplification of the ion trap control electronics.

[0010] Alternatively, the use of multiple traps in a single parallel array can offset some of the loss in ion storage capacity with miniaturization. In the standard mass-ejection analysis mode, parallel arrays of miniature CITs having the same trap dimensions can be scanned to provide simultaneous ejection of similar ions from all traps, providing improved sensitivity.

[0011] Serial arrays of such miniature CITs can be also be used for ion storage, mass selection, and ion reaction and product ion analysis. For example, serial arrays of miniature CITs, wherein ions trapped in a first CIT are transferred to a second CIT, can be used to provide multiple stages of mass isolation and analysis in a tandem or multistage capability.

[0012] However, precision machining methods only provide arrays of miniature CITs comprising a few millimeter-