

MICROCHIP ION TRAP MASS SPECTROMETRY

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Abstract

We have been exploring the use of cylindrical ion traps of 1-mm diameter and smaller for mass spectrometry. These miniature ion traps have dimensions that are comparable to the thickness of the substrates used in microfluidic devices and their simple structure is amenable to microfabrication techniques. Operating voltages are lower than for conventional ion traps while RF frequency and working pressure are higher, making miniaturized electronics and vacuum systems possible as well. Mass resolution comparable to or better than for laboratory ion trap mass spectrometers has been demonstrated. The number of ions that can be stored in traps of equal energy depth scales as the radius of the cavity rather than the volume. This property makes two-dimensional arrays of small ion traps attractive for increased dynamic range. Several examples of miniature ion traps, methods of sample ionization, mass analysis, and ion detection will be described.

Keywords: Mass spectrometry, ion trap

1. Introduction

In the more than 10 years since ion trap mass spectrometers were commercially introduced as mass selective detectors for gas chromatographs, they have been shown to have applications as field instruments as well as in the laboratory. Several instrument characteristics have made ion trap mass spectrometers especially powerful for analysis of trace molecular species. First, they can operate at a pressure of up to 10^{-3} torr, several orders of magnitude higher than other mass spectrometers. This results in a proportionally higher sensitivity because more analyte molecules will be present within the trap at a given time. Secondly, the ion trap is a very efficient device for tandem mass spectrometry, or MS/MS. In this process, ions of a particular mass are isolated in the trap by ejecting all other ions, then the remaining ions of interest are collisionally dissociated under conditions where the fragment ions can be trapped and mass analyzed. MS/MS can also be achieved through ion-molecule reactions. The resulting information helps to positively identify the ions present even when the original sample was a complex mixture.

We have recently been exploring the capabilities of micro ion traps of millimeter to submillimeter inner dimension for mass spectrometry applications.^{1,2} The micro ion traps are functionally equivalent to their laboratory-sized relatives but operate at higher

frequency and lower voltage, so that the electronics package can be considerably smaller in size. Vacuum requirements are reduced because of the smaller chamber size. Mass resolution is comparable to or better than that obtained with the laboratory systems, the micro traps operate at the same or higher pressure, and single ions can be detected. Sensitivity for trace constituents in the atmosphere under various sampling conditions has yet to be determined. We have shown that a two-dimensional array of equivalent ion traps can be operated in parallel for enhanced storage capacity (sensitivity). While the traps studied so far have been assembled from conventionally machined parts, the dimensions and form are amenable to microfabrication for higher precision and eventual integration with the ion source and detector.

2. Experimental

The ion trap electrodes were fabricated as described in Ref. 2 except that the outer diameter was 12.7 mm instead of 25.4 mm so that the assembly would fit in a 1.33-inch mini-Conflat vacuum cube. A rhenium filament served as an electron emitter for sample ionization and a fragment of a microchannel plate was used as an ion detector. In the usual fashion,³ ions generated by the electron beam were trapped, the range of m/z of the trapped ions depending on the RF and DC voltages applied to the trap electrodes. After an integration time of typically 20 ms, the voltages on the ion trap were scanned so that ions were ejected to the detector at different times depending on their mass to yield a mass spectrum of the initially trapped ions. Mass spectra were obtained by scanning either the RF voltage or a DC voltage applied between the ring electrode and endcaps. Helium was used as a buffer gas at pressures from 10^{-2} torr to greater than 10^{-1} torr. Samples studied included xenon gas and various volatile organic compounds.

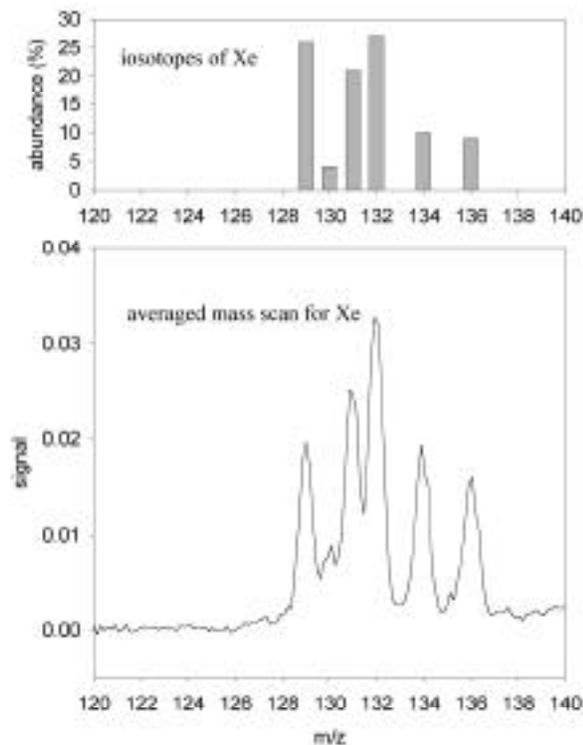


Figure 1. Mass spectrum of xenon isotopes.

4. Results and discussion

An example of a mass spectrum of xenon isotopes is shown in Fig. 1. This spectrum was obtained by decreasing the RF voltage on the ring electrode (DC voltage = 0) so that the ions would selectively be ejected when a nonlinear resonance occurred at $\nu = 0.5$. The spectrum was averaged over several hundred scans, so that isotope ratios could be determined with higher precision than for single scans.

It was also possible to obtain mass spectra by scanning a DC voltage on the ring electrode while the RF voltage was of constant amplitude. This scan is electronically simpler to implement than the previous scan. A mass spectrum of dodecane obtained in this way is shown in Fig. 2. The various peaks correspond to fragment ions with different numbers of carbon atoms with unresolved attached hydrogen atoms.

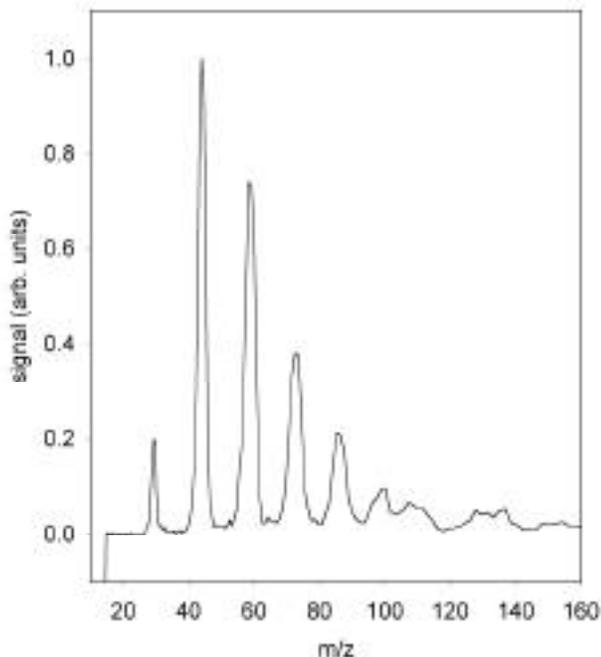


Figure 2. Mass spectrum of dodecane

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References

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