Miniature Chemical Detector with High Yield Preconcentration

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Introduction

A next generation miniature chemical detection system has been developed using an ion trap mass spectrometer of cylindrical geometry[1] as the core of the device. Sample introduction into the trap volume is achieved by one of two means, either through a semi-permeable membrane or directly via a pulsed valve inlet. Currently the trap volume is of 1 mm dimensions. Since air enters the trap through the membrane, it is also the buffer gas that cools the ions in the trap as well.

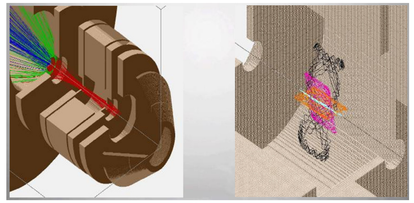


Figure 1 Simulation of the ion motion within the trap. Data acquired using customized software.

A typical operating vacuum pressure of 10^{-3} Torr or less has been achieved using a miniature turbopump with a pumping speed of 10 l/s backed by a compatible diaphragm pump and electronic control system made by Pfeiffer Vacuum.

Over the development period of the whole system the electronics have been miniaturized and are now reduced to two boards of 192 cm^2 and 103 cm^2 footprint. Since one of the major goals has been to reduce the weight of the complete system, a total weight is now less than 15 lbs while the overall physical dimensions are 30 cm deep, 15 cm tall and 8 cm wide on the first production prototype.

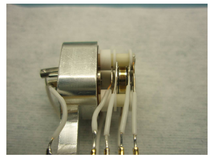


Figure 2 Current Ion Trap Design

With air as the buffer gas a resolution of <1 amu has been regularly achieved up to a mass of 450 amu. See Figure 4 which shows the current single MS capabilities. Because the sample is being introduced un-ionized with the matrix gas, the ionization process chosen for this initial instrument was electron ionization of 70 eV energy. Thus the spectral characteristics of the analyte molecules consist primarily of characteristic fragment ions plus some residual unfragmented parent ions that are searchable against NIST library spectra. See Figure 5 for an illustrative example.

Figure 3 Current Prototype Unit

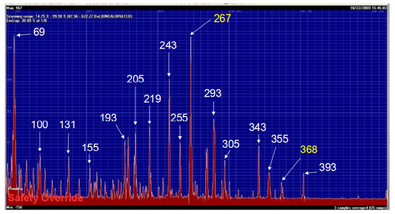


Figure 4 An example of a spectrum illustrating the resolution and the mass range, using perfluorodecalin.

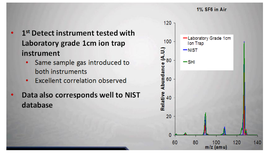
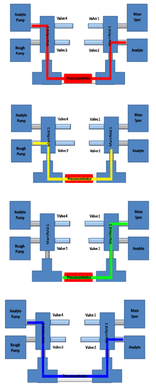


Figure 5 Comparison of SF_6 spectra showing NIST correspondence.

In designing a miniaturized system no compromise has been made for either the target mass range (typically airborne molecules) or the resolution achievable. However, the small size of the trap volume does limit the sensitivity to the low ppm or high ppb concentration range. For some applications this is acceptable but for many others much lower concentrations of analytes must be observable.

[1] Moxom, J.; Verbeck, G.F.; Whitten, W.B., "Miniaturization of Mass Spectrometers Based on Submillimeter Cylindrical Ion Traps" 53rd ASMS Conference on Mass Spectrometry, San Antonio, TX, June 5-9, 2005.

A novel pre-concentrator has been designed that leverages the selective sorptive capabilities of advanced materials with a novel design that significantly reduces the analysis time compared to currently deployed instruments. In the design sorbent materials are placed in a tube with a heating element. The electrical leads of the heater is connected to a power supply controlled by a computer system. Because the tube housing the sorbent is evacuated thus minimizing the dead volume effect prior to thermal desorption, the overall concentration gain is a product of the adsorption and evacuation gains yielding a typical total gain in the range of 10^4. Typical analysis times are less than 30 seconds.



- **Absorption**
  Flow sample over pre-concentrator
- **Evacuation**
  Remove air surrounding pre concentrator
- **Desorption/Analysis of Sorbent to liberate analyte and measure with mass spec**
- **Cooling and Flushing**
  Sorbent coating cooled, residual analyte is removed

Figure 8 PreConcentrator Analysis Cycle

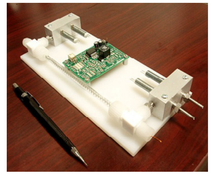


Figure 7 Photograph of the prototype adsorber unit

Future Directions

-The current design has shown MS^n isolation/fragmentation performance which will be optimized and automated.
-Develop a passive vacuum pumping system.
-The current software/control system has been engineered in-house with the capability to interact with networks e.g. Wi-Fi, 3G cell phones. Further work is planned to make it secure over distributed sensor networks.
-Simplified user interface and automated mass calibration
-Larger trap volume design
-Introduction of externally ionized molecules (APCI and electrospray for example)
-Further miniaturization of architecture including MEMS techniques

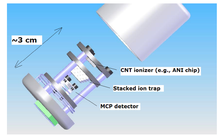


Figure 9 Further Miniaturization Plan

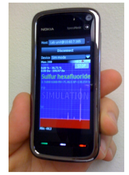


Figure 10 Direct control of systems using cell phone technology