Micro ion traps for real-time chemical analysis in harsh environments
STL-002-20, Year 2 of 3

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Challenge

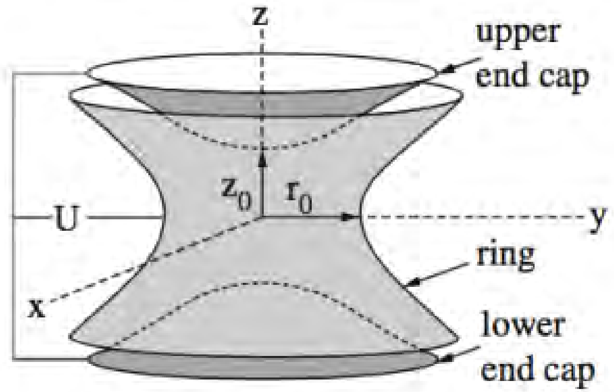
- Currently, remote real-time chemical analysis is possible, but the sensors used are nonspecific. They are capable of sensing a family of compounds, such as volatile organics, but are not able to identify the actual chemicals being analyzed.
- It is also possible to capture the chemical in an adsorption trap or sampling bag and return it to the base of operations for analysis with laboratory techniques, such as gas chromatography-mass spectrometry, at a later time.
- A device capable of providing analytical specificity in the field and transmitting the data back to the operator would bridge this gap and be a significant improvement for operational scenarios where chemical analysis is required.

Innovation

- To maintain as small a footprint for the system as possible, we have designed the unit to have trapping regions measuring hundreds of microns. In contrast, typical ion traps have trapping regions measuring several centimeters.
- The unit is being designed to be small and lightweight for remote operation, such as on UAS platforms, with the potential of making measurements in harsh environments.
- The system is being engineered to use relatively inexpensive components that are lightweight and low power, with the goal of being smaller and lighter than any portable mass spectrometer that is currently commercially available.

Technical Approach

- A Paul-type ion trap functions by confining ions in a region of space between three electrodes using a combination of DC and RF electric fields. The DC component of the field is applied to the two end cap electrodes, confining ions axially, and the RF is applied to the ring electrode.



$$a_z = \frac{-16eU}{m(r_0^2 + 2z_0^2)\Omega^2} \qquad q_z = \frac{8eV}{m(r_0^2 + 2z_0^2)\Omega^2}$$

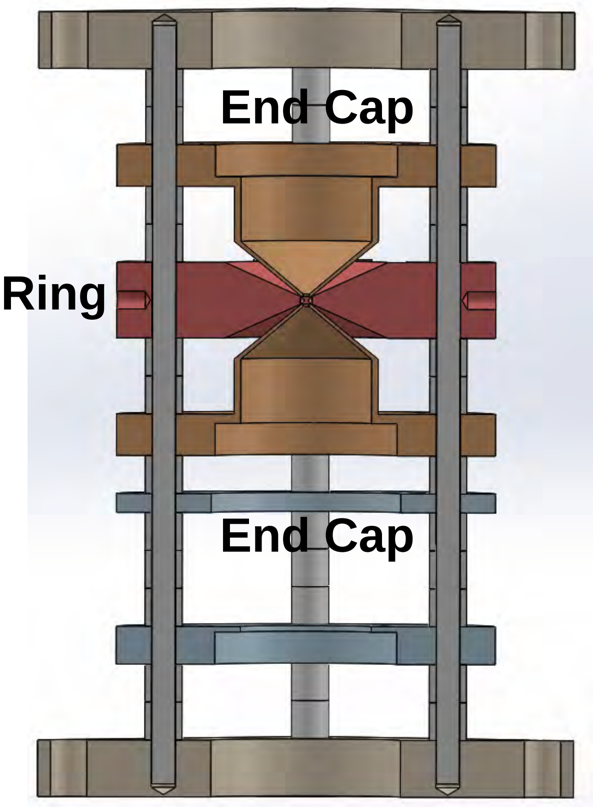
- A mass spectrum of the ions is obtained as the trapping field is altered in a way that destabilizes the trajectories of the ions according to their mass-to-charge ratio (m/z). Ions are then sequentially ejected from the trap and are detected.

Year 1 Summary

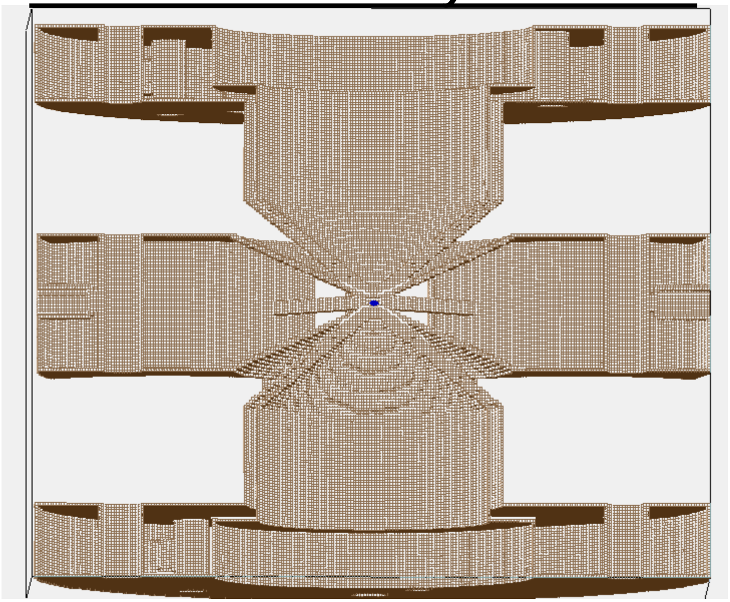
- Achieved stable trapping conditions for ion traps having dimension ranging from 200–500 µm using ion trajectory simulations (Simion 8). The simulations suggest that the RF frequency must increase as the trap dimensions decrease.
- The simulations also suggest that stable trapping conditions exist at pressures up to 100 Torr. Experimentally verified this theoretical result using an existing laboratory instrument (30 Torr).
- Used an ion trap with a 1 mm trapping region, designed and built as part of a previous effort, as a test platform to verify the results of the simulations and to explore techniques for ejecting the ions from the trap as a function of mass.

Results

SolidWorks Model of Micro Trap (z_0 = 250 µm)

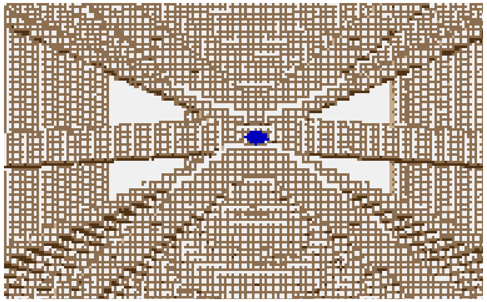


Simion Simulation Using SolidModel Geometry at 100 Torr



Freq = 25 MHz   Amp = 200 V

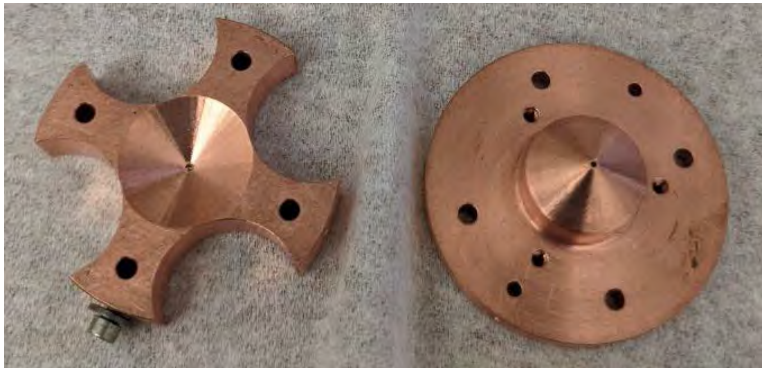
3x Zoom of Trap Volume



Results

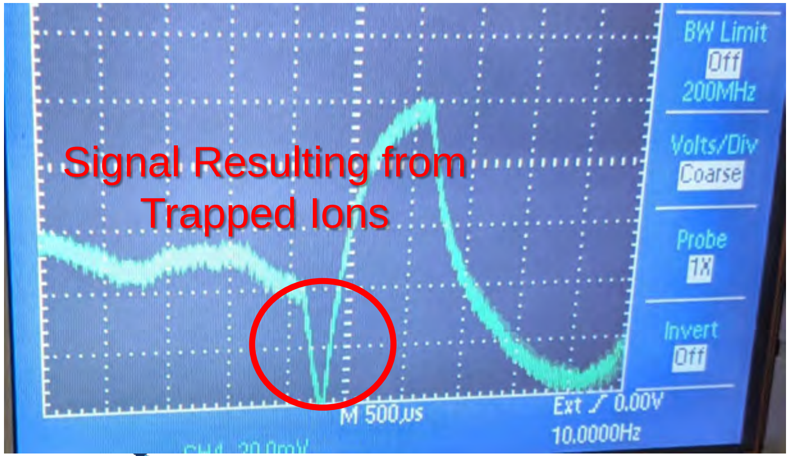
Micro Trap Assembly (z_0 = 250 µm)

Micro Trap Components

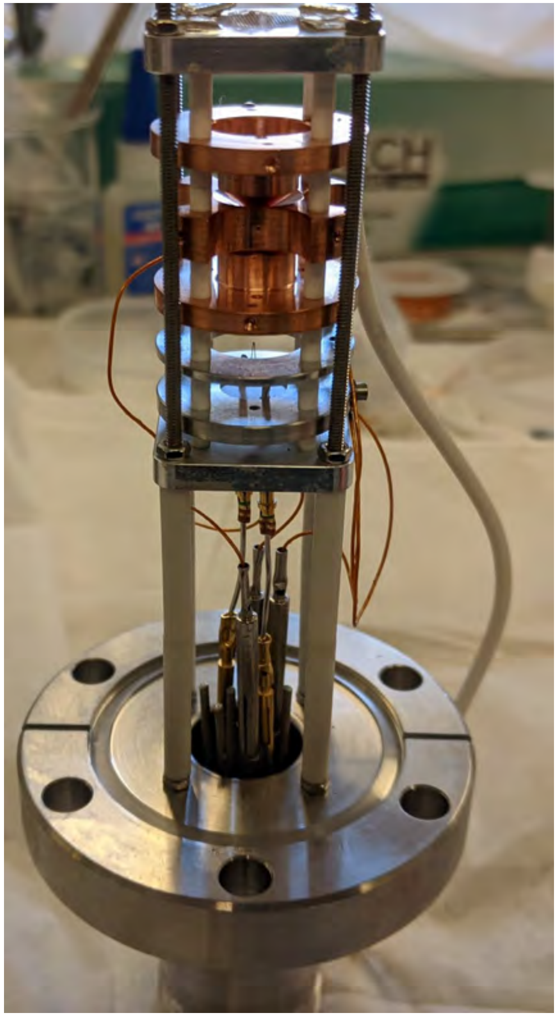


Ring ***End Cap***

First Signal



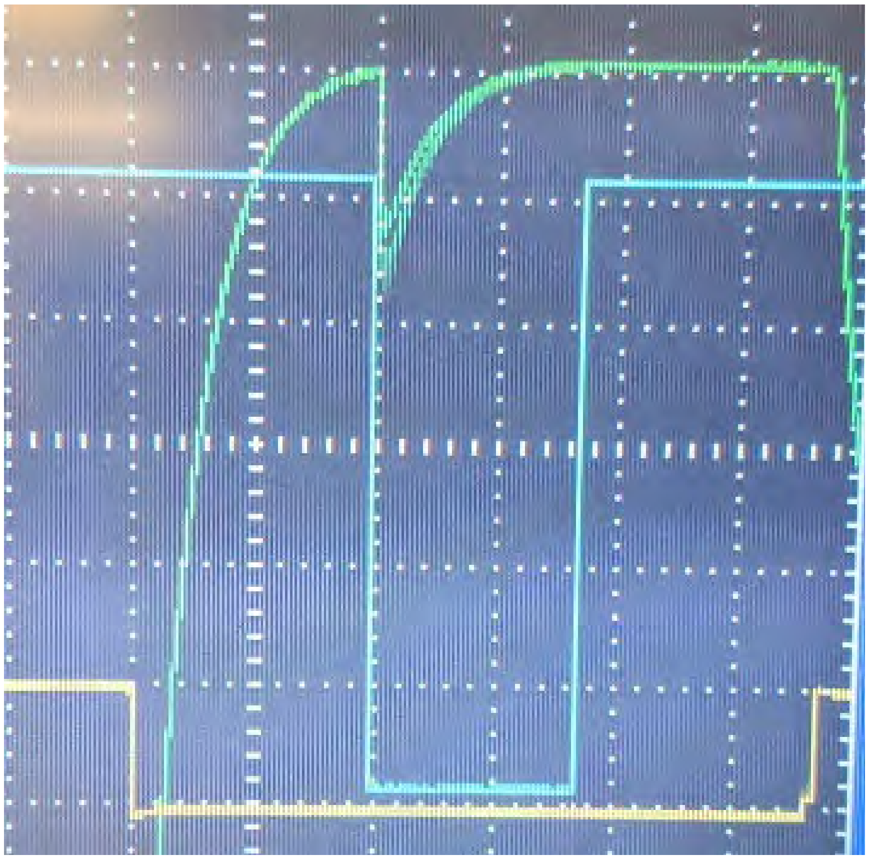
Micro Trap Assembly



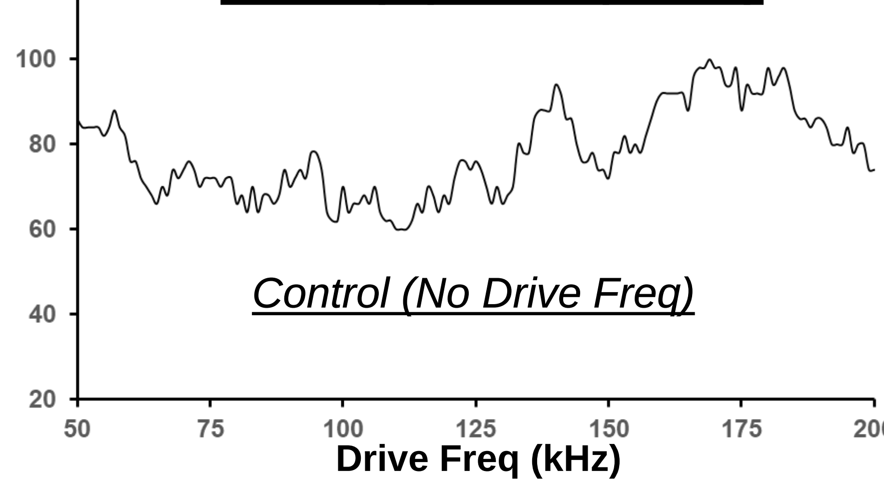
Results

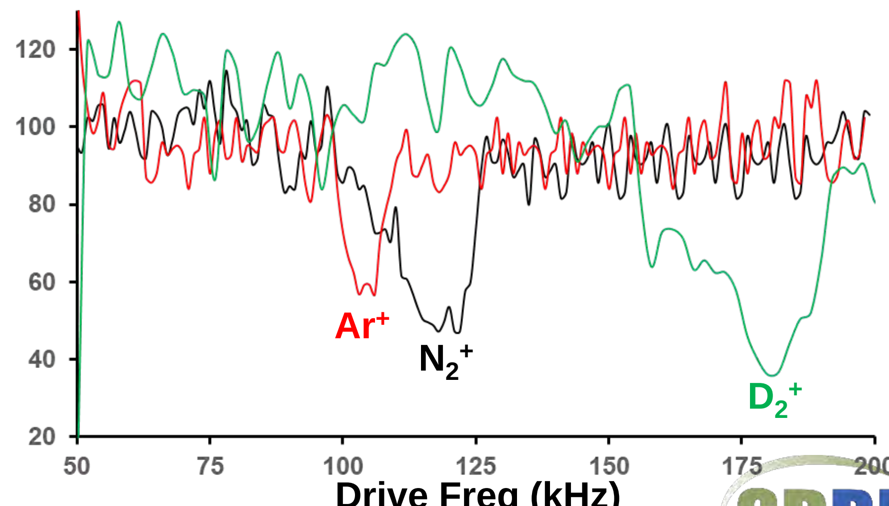
Improved Performance of the System

Improved Trapping Efficiency and Signal to Noise



Mass-Selective Ejection from the Trap (Mass Spectra)

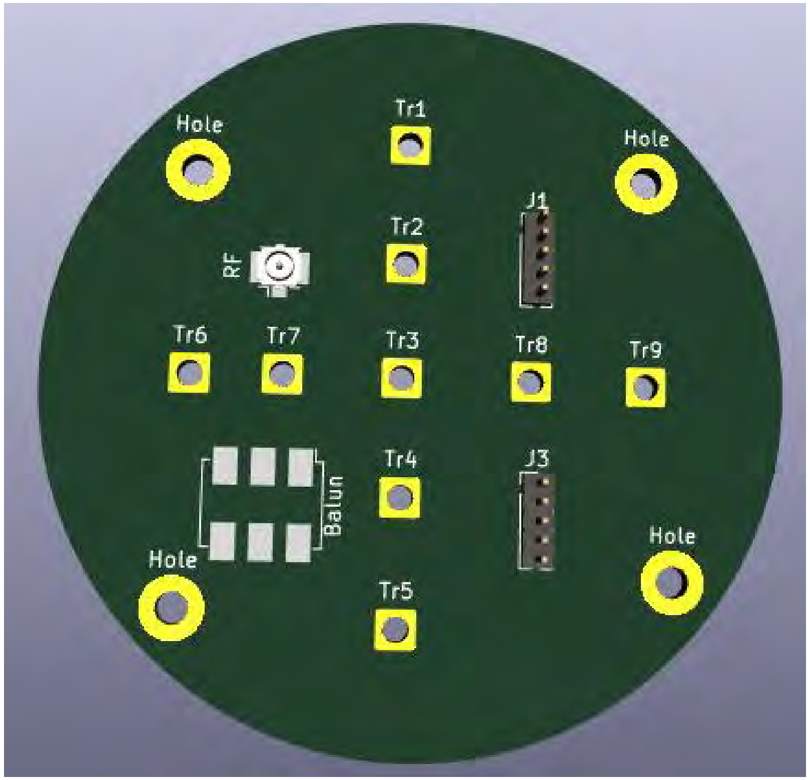




Results

Micro Trap Array (z_0 = 250 µm)

Printed Circuit Board (PCB)



- The PCB containing an array of nine (Tr1–Tr9 shown in yellow) micro ion traps.
- The dimensions of the PCB is 1 inch in diameter and 0.125 inches thick.
- All circuitry needed to provide the electric fields to the various component of the device is provided as part of the PCB layout.

Summary of Results, Path Forward

- Using knowledge gained from Year 1 results, we designed and assembled a prototype of the micro ion trap, with z_0 = 250 µm, during Year 2.
- Testing of the prototype is currently in progress, and the data acquired with an RF frequency of 25 MHz and amplitude of 40 V_p reveal that ions are successfully being confined in the micro trap.
- We are currently working on optimizing experimental conditions for efficient ion confinement and determining the optimal parameters for mass-selective ejection from the trap to generate mass spectra.
- We have designed and will soon fabricate a PCB that contains an array of nine micro ion traps. The PCB is 1 inch in diameter and 0.125 inches thick.

Impact

- A proposal to continue developing the micro ion trap system using the knowledge acquired from results obtained in Years 1 and 2 has been accepted.
- The primary focus of Year 3 will be completing the design and assembly of the overall system (ionization source, trap array, and detector) as well as testing the capabilities of the unit (lab and field).