

**Development of a Hand-Portable Mass Spectrometer for  
Nonproliferation/Safeguards Applications**

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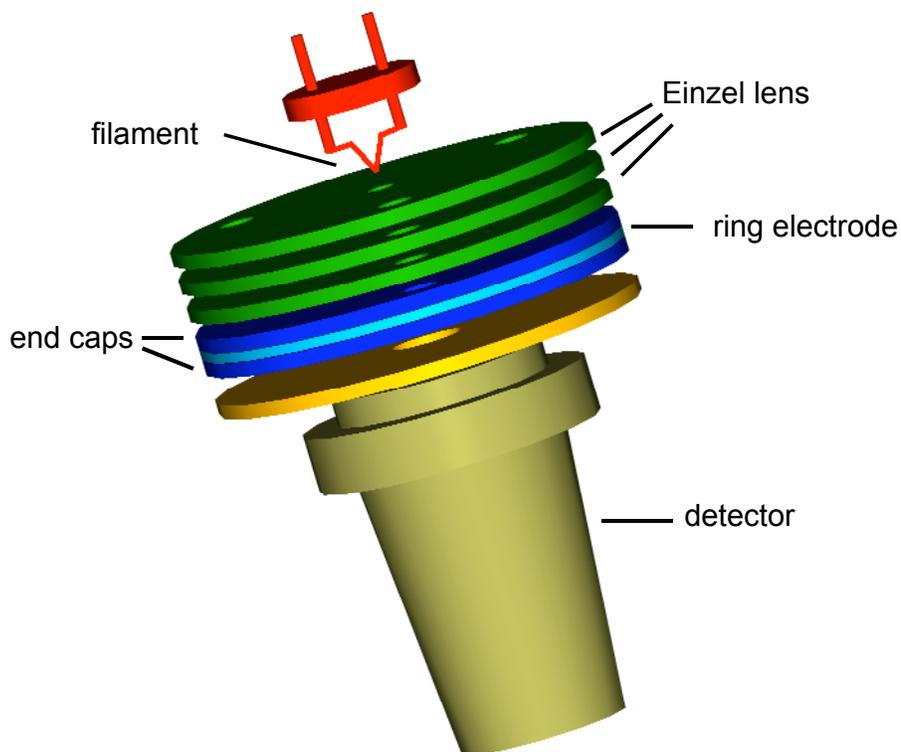
**ABSTRACT**

We are developing a fieldable, battery-powered mass spectrometer based on miniature ion trap technology. A particular application we are addressing is the isotopic analysis of  $\text{UF}_6$ . One of the challenges being faced is to extend the mass range while maintaining the mass resolution required for accurate isotope ratio determinations. Another is the chemical reactivity of  $\text{UF}_6$  that places additional restrictions on the components of the mass analyzer. Results of experiments with different micro ion trap configurations and nonradiological surrogates are reported.

## INTRODUCTION

Mass spectrometry with isotopic resolution is the measurement of choice for determining the degree of enrichment of a  $\text{UF}_6$  sample because isotope ratios can be obtained directly from the mass spectral data with little or no correction. However, such measurements usually require that a sample be collected and transported to the mass spectrometer for analysis. For a number of years, we have been exploring the use of mass analyzers based on micro ion traps with diameters of millimeters or less. We have found that such ion trap mass spectrometers can yield mass resolution comparable to that of a laboratory mass spectrometer, while operating at higher pressure and frequency and at lower voltage. These features are attractive for the construction of portable systems. We are currently developing a prototype version of a fieldable, battery-powered mass spectrometer. The purpose of this paper is to describe our progress in this endeavor, in particular, towards an instrument for on-site isotopic analysis of  $\text{UF}_6$ .

An ion trap mass spectrometer requires no magnetic field and operates in a simple way [1]. The mass analyzer consists of three electrodes, a ring electrode and two end caps, separated by Kaptan insulating film, as shown in the drawing in Fig. 1. The trap itself is a 1-mm diameter hole drilled in the center of the ring electrode [2]. Smaller holes in the



*Fig. 1. Drawing of an ion trap mass analyzer assembly.*

two end caps permit ions to be created in the trap and be ejected. A radiofrequency voltage applied to the ring electrode alternately attracts and repels an ion with respect to

the center of the electrodes [1]. If the frequency of the voltage is sufficiently high, the ion will reverse direction before passing through the endcaps, thus becoming trapped. For a given voltage and frequency, ions of a range of masses will have stable trajectories. If the voltage is increased, lighter ions will become unstable and be ejected. By ramping the voltage, we can detect ejected ions in order of their mass and thus obtain a mass spectrum. We have shown that excellent mass resolution can be obtained with a 1-mm diameter trap when a supplementary radiofrequency voltage at 1/4 of the drive frequency is applied between the two endcaps. Ions are then ejected at a nonlinear resonance of the cylindrical ion trap [2].

A functional mass spectrometer requires additional components besides the ion trap itself. A vacuum system is necessary to reduce the rate of momentum-changing collisions of the ions. Some means of sample introduction and ion formation as well as a detector for the ejected ions must be provided. Finally, circuitry to generate the voltages for the ion trap,

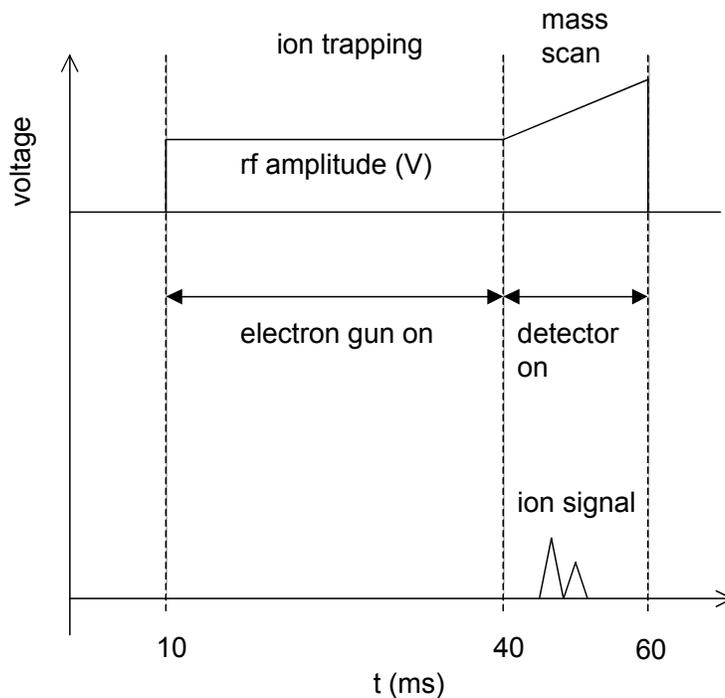


Fig. 2. Timing diagram for micro ion trap operation.

process the signal from the ion detector, and convert the signals into archival mass spectral data must be developed. We have shown in Fig. 1 an electron gun formed from a combination of thermionic electron emitter and accelerating and focusing electrodes. The three electrodes between the filament and the trap form an Einzel lens that focuses the electron beam into the center of the ion trap. The accelerated electrons generate ions from a gaseous sample within the trap electrodes by electron impact. Ions ejected from the trap are detected by a channel electron multiplier, also shown in Fig. 1, that amplifies the ion current.

## FIELDABLE PROTOTYPE

The vacuum system for the prototype instrument is based on a battery-powered pumping system from MKS Instruments, Inc. A turbomolecular primary pump is backed by a

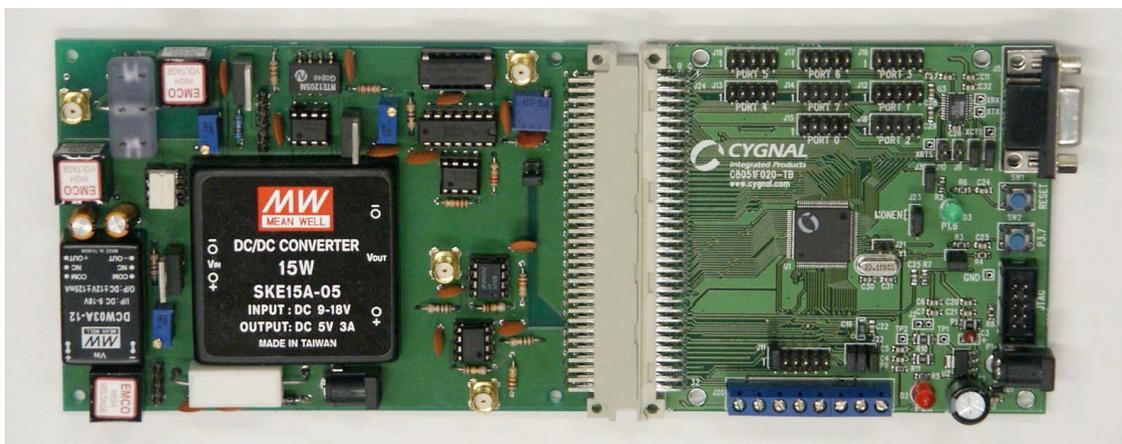


Fig. 3. RF and timing electronics.

scroll pump. The system can achieve a vacuum of  $10^{-6}$  Torr when completely closed. A gaseous sample is admitted into the chamber housing the mass analyzer through a leak valve. The system is powered by two 12-V rechargeable batteries with a 2-hour life for the vacuum system alone, approximately one hour when the electronics package is connected.

The electronics package for the portable prototype uses a microprocessor to generate the amplitude of the radiofrequency voltage for the ion trap and to gate the electron gun and ion detector so that these are turned on and off at the appropriate times. A timing diagram of the analysis process is shown in Fig. 2. While ions are being created, the trap amplitude is maintained at a level sufficient to trap the desired ions. After a certain time, the electron gun is turned off, the ion detector turned on, and the radiofrequency amplitude is increased at a linear rate until all of the ions have been ejected. The ion current from the detector is amplified and signal averaged. The process is then repeated until the desired signal-to-noise ratio has been attained. A photograph of the radiofrequency and signal circuitry is shown in Fig. 3. The microprocessor that



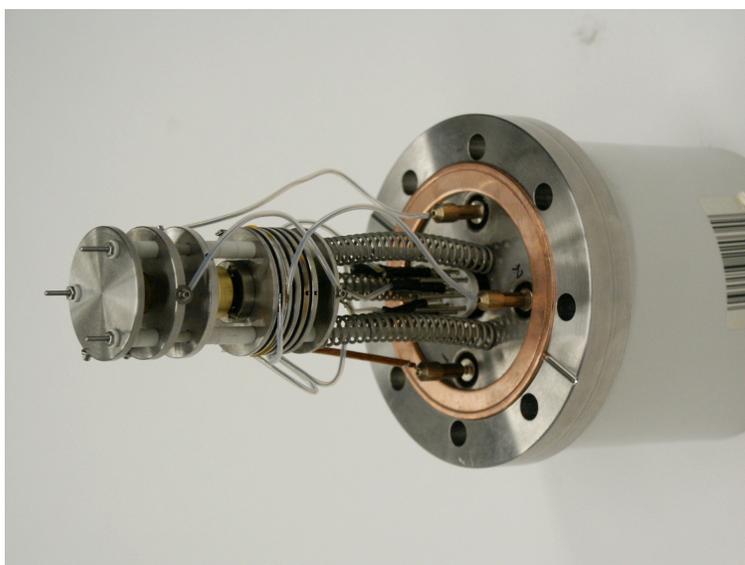
Fig. 4. Battery-powered prototype.

controls the measurements is at the right in the figure. Circuits to power the electron gun filament, supply high voltage to the detector and electron gun lens, and a power amplifier for the radiofrequency ion trap voltage are not shown.

A photograph of the battery-powered fieldable prototype under construction is shown in Fig. 4. The electronics boards are mounted in the space below the two vacuum pumps. The two batteries straddle the pumps. The mass analyzer with electron gun and channel electron multiplier are inside the cubical chamber. The assembly weighs approximately 20 lb and is 14 inches long.

## UF<sub>6</sub> EXPERIMENTS

The development of a mass spectrometer for UF<sub>6</sub> analysis is made more complicated



*Fig. 5. Micro ion trap mass analyzer for experiments at the UF<sub>6</sub> Test Loop.*

because of radiological contamination. Our mass spectrometry laboratory is in a nonradiological area. Therefore, we have chosen to construct two vacuum systems and mass analyzers, one set for use in our laboratory with surrogate samples and one for UF<sub>6</sub> experiments at the ORNL UF<sub>6</sub> Test Loop. The electronics instrumentation for the experiments is not subject to contamination and can be moved from one experiment to the other.

When a satisfactory analyzer configuration has been achieved, these developments will be incorporated into the portable prototype mass spectrometer for field tests.

A photograph of a micro ion trap mass analyzer that has been constructed for the present UF<sub>6</sub> experiments is shown in Fig. 5. This assembly is mounted on a 4.5-inch Conflat flange for experiments at the ORNL UF<sub>6</sub> Test Loop Facility. In the figure, the channel electron multiplier is at the left, farthest from the flange, and the electron gun is to the right of the three ion trap electrodes.

So far, the experiments performed at the ORNL UF<sub>6</sub> Test Loop Facility have been to test the ionization source and detector for stability in the presence of the corrosive UF<sub>6</sub> vapor. We found that there was some initial degradation of sensitivity with time but that the measured ion current stabilized after one hour of exposure. Moderate changes in

sensitivity with time are not detrimental because it is only the ratio of  $^{235}\text{U}$  to  $^{238}\text{U}$  signals that is important.

#### **ACKNOWLEDGEMENT**

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