

Miniature Mass Spectrometer (MMS) For Contaminant Gas Monitoring

Mahadeva P Sinha , Jet Propulsion Laboratory, Pasadena, California

ABSTRACT

A small, low power, low maintenance sensor for monitoring air quality in human exploration and planetary habitats is being developed. The sensor is based on the technologies of a focal plane mass analyzer, and an array detector. It is a **nonscanning** type of mass spectrometer measuring signals at all masses simultaneously. It will possess high sensitivity (ppb concentration levels). The miniature mass spectrometer (**MMS**) can also be used for chemical and isotopic analysis of planetary atmosphere, and surface /rock materials. MMS, when fully developed, will weigh 0.5-0.7 kg and consume ~ 1 W of power.

INTRODUCTION

The human missions to the space station, and to other planets will be of longer duration than missions so far undertaken. In addition to the biological activities, various operations in the **laboratory** modules (space station), and outgassing of materials will release harmful chemicals in the atmosphere of the astronauts' habitats. These chemicals will affect their safety and functional capabilities. It is, therefore, critical that the habitats of the crew be monitored, and maintained at a healthy level. Some of the contaminants affect human health at very low concentrations (for example, benzene, **acrolein**, formaldehyde, furan, HCN, MMH).

Monitoring of the atmosphere inside the cabin/module needs the development of a **sensor** that could detect small quantities of toxic/hazardous chemicals. These small concentration of toxic chemical could build up to hazardous levels in long term habitations. The NASA Maximum Allowable Concentrations (**MACs**) of chemicals for missions up to 7 days range from 10 ppb to 100 ppm [1], For longer mission duration the MACs for the various chemicals will be lower than the above values. Furthermore, since all the future monitoring requirements have not been identified, it is important that the new technology be applicable to a wide range of contaminants. Besides its

general applicability, the method should possess sensitivity to detect at ppb level and should also possess specificity to identify chemicals. Mass spectrometry is expected to meet these requirements.

Mass spectrometry is a powerful analytical technique that is used for the identification and quantitative measurements of compounds. In this method, the sample vapor is introduced into the vacuum chamber of the ion source through an inlet where the sample molecules are ionized by electron impactation. The positive ions are propelled into an analyzer where they are sorted according to their mass-to-charge ratios. The analyzers can be classified into two types: scanning and **nonscanning**. In a scanning mass analyzer (**e.g.** quadruple mass spectrometer), the signals at all the other masses are discarded while the signal at one mass is being measured. Less than one percent of the signal is utilized, The instrument, therefore, has a very low duty cycle. On the contrary, in a nonscanning mass spectrometer, signals at different mass-ions are measured simultaneously with an array detector after their spatial separation. A duty cycle of 100 % is achieved and consequently, a nonscanning mass spectrometer possesses higher sensitivity (defectivity). It is also suited for the measurement of composition varying with time, and for the measurement of transient samples.

Our approach towards the development of a miniature mass spectrometer for monitoring contaminants uses a nonscanning (focal plane) mass analyzer and an array detector. Ions of different masses are spatially separated along the focal plane and their intensities are measured with an array detector with high spatial resolution. Three types of array detectors are being considered for this work.

The details of the miniature mass spectrometer (**MMS**) and the results of mass spectral measurements with MMS are described below.

MAIN SECTION

The miniature mass spectrometer (MMS), developed at JPL, is based on a double sector mass analyzer (**Mattauch-Herzog geometry**).

The analyzer is shown schematically in Fig. 1.

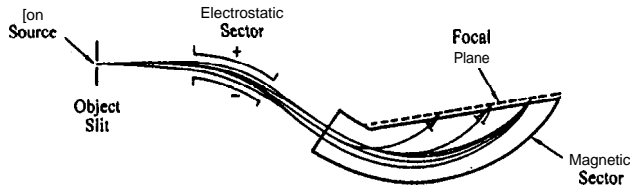


Figure 1: Focal Plane Mass Spectrometer of **Mattauch-Herzog Geometry**

The ions, formed by electron impact on gaseous molecules in the ion source, are accelerated into a beam that enters the electrostatic sector instrument. Parallel rays of ions emerge from the electrostatic sector and enter the magnetic sector where the ions of different masses are deflected along circular paths of different radii. The different mass ions are thus spatially separated along the focal plane located at the exit of the magnet. This design of the analyzer provides both direction and **energy/velocity** focusing for the ions at the focal plane as shown in the Fig. 1 (i.e., the ions of the same mass in the ion beam starting from the source with different directions and a spread in energy are brought to focus at the focal plane). The feature relaxes the stringent requirement of controlling the spread in ion energy (as required in a single sector mass analyzer) and thus simplifies the design of the source. The resolution of the MMS is estimated to be ~ 400 with $\pm 1V$ of ion energy spread,

We have successfully overcome the large size and weight problems historically associated with a **magnetic sector**. This was accomplished by using emerging magnetic materials and novel design features for the analyzer [2].

The **electrostatic sector (ESA)** was fabricated from a single piece. The ion source, ESA, and the magnetic sector are all mounted on a single plate. This arrangement facilitates the alignment and makes the analyzer compact and rugged. Figure 2 shows a photograph of the analyzer.

The MMS has focal length of 2.5 cm and covers a mass ratio M_{max}/M_{min} of 6. The MMS can measure, for example, all the masses from 30 u to 180 u simultaneously. Different mass ranges can be covered by stepping the ion energy in the ion source. Mass ratio/range can be extended by increasing the length of the focal plane.

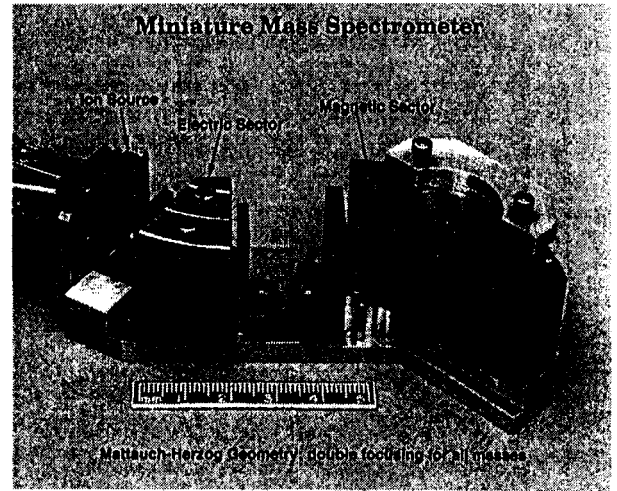


Figure 2: Photograph of the miniature mass spectrograph

Suitability of different types of array detector are being investigated. These include a new **electro-optical** ion detector [3], array detector fabricated by metal anodes deposition on a silicon wafer along with its associated electronics [4], and a array detector based on Active Pixel Sensor (APS) elements [5,6]. Here the light collecting diode will be replaced by metal strips to collect ion images.

RESULTS - The performance of the analyzer has been demonstrated. For this purpose a conventional ion source with **thermionic** electron emitter was interfaced with the analyzer (see Fig. 2). The detector, consisting of a **channeltron** with a slit in front of it, was placed at the focal plane. The detector assembly was mounted on micrometer support in order to move them in operation. Their translation allowed the measurement of intensities of different mass ions separated along the focal plane, Figures 3-5 show the mass spectra thus measured by MMS.

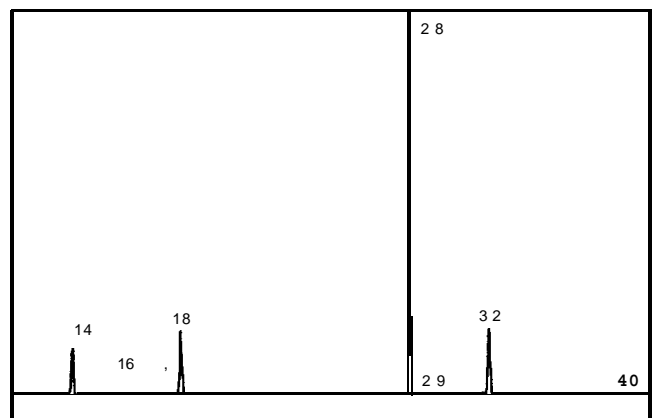


Figure 3: Mass spectrum of air measured by MMS

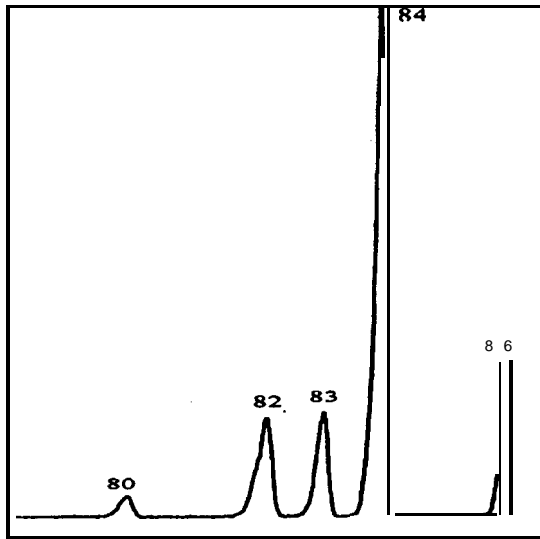


Figure 4: Krypton isotope mass spectrum measured by MMS

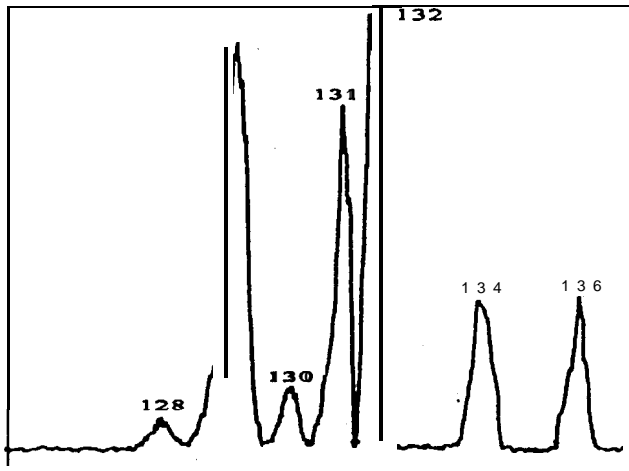


Figure 5: Xenon isotopes mass spectrum measured by MMS.

DISCUSSIONS - The results show the resolution of the MMS to be ~ 312 . The base line resolution of the instrument will enable high quality isotope ratios measurements of various elements. The mass of the present design of the analyzer shown in figure 2 is 230 g.

A conventional ion source based on thermionic emission of electrons from an electrically heated filament was used. However, this requires a power in the range of 3-4 W for the generation of needed 100-200 μA of electron emission current,

Work on the development of a low power ion source (0.5- 1.0 W) is presently being performed in our laboratory. A suitable array detector as discussed above is also being developed. The expected performance of

the MMS with the new ion source and the array detector is listed in Table I.

Table I

Weight	500-700 g (Includes Power Supply And Pump)
Power	1 - 2 W (operational), m W (standby)
MMS dimensions	10 cm x 5 cm x 4 cm
Ion source	Thermionic
Mass range	2-250u
Sensitivity	Single ion measurement
Resolution	-400

Besides its performance listed above, the MMS is ideal for exploiting the advantages offered by a microbore capillary column ($\leq 50 \mu\text{m}$ i.d.) gas chromatography. This is enabled by the high sensitivity and temporal resolution of the miniature mass spectrometer. A microbore column offers high efficiency for separating compounds from their mixture [7]. At the same time such a column due to its small cross sectional area introduces a extremely small gas load into the ion source, and thereby, minimizes the pumping needs for the mass spectrometer. A short length (1-3 m) of a microbore capillary column provides adequate separation for volatile organic compounds in $< 60\text{s}$. The peaks of separated compounds eluting from the such a short microbore column are particularly narrow and closely spaced. Their mass spectral measurements with a scanning type of MS is generally not feasible [8]. Simultaneity of measurement for different mass ions with 100% duty cycle will overcome this problem. Combination of the MMS with this column will provide a fast, high performance GC-MS instrument without significant increase in the mass, power and pumping need for the mass spectrometer. Such a microbore capillary column gas chromatography and MMS combination will be immensely useful for monitoring, if the chemicals in the astronauts habitats are found to contain a mixture of many compounds.

ACKNOWLEDGMENTS

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

REFERENCES

- 1, Listing of Spacecraft Maximum Allowable Trace Gas Concentrations, Johnson Space Center Houston, TX, Document No. 20584; also NASA Document No. NHB-8060. I B, and references therein.

2. Sinha, M. P., and Tomassian, A. D. (1991). Rev, Sci. Instrum., 62, No. 11, 2618.
3. Sin ha, M. P. *Improved ion detector for mass spectrometers* , accepted for publication in NASA Tech Brief (1997), NPO-19787.
4. K. Birkinshaw (1994). *Silicon technology in ion deflection - a high resolution detector array*, Int. J. Mass Spectrom. Ion Ion Processes, 132, 193.
5. Fossum, E. R. (1994). *Assessment of Image sensor Technology for Future NASA missions*, in Charged-Coupled Devices and Solid State Optical Sensors IV, Proc. SPIE vol. 2172, pp. 38-53.
6. Fossum, E. R. (1994). *Ultra low power imaging systems using CMOS image sensor technology*, in Advanced Microdevices and Space Science Sensors, Proc. SPIE cot, 2267, pp. 107-111.
7. Sinha, M. P., and Gutnikov, G. (1992). *Role of Microbore Capillary Column in the Development of a Portable Gas Chromatograph-Mass Spectrometer*, J. Microcol. Sep. 4, No 5,405.
8. Sinha, M. P., and Gutnikov, G. (1991), Anal. Chem., 63, No, 18,2012.