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Instruments for highly sensitive investigations of volatiles and planetary solids

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Abstract

Two miniature time-of-flight mass spectrometers, laser ablation/ionisation mass analyser (**LMS**) and a neutral gas mass spectrometer (**NGMS**), which were designed for chemical analysis of planetary solids and gaseous samples, respectively, will be introduced. LMS can perform full elemental and isotopic analysis of planetary materials (ablation mode) and can be used for detection of molecular compounds (desorption mode), which can be deposited on surfaces of planetary rocks. Current performance evaluations shows a high mass resolution <u>m/Δm~500</u> and the effective dynamic range of higher than 8 decades. The limits of the detection for both, metallic and nonmetallic (e.g., B, C, S, P, Si) elements are at some <u>tens of ppb</u>. The LMS instrument can also perform analysis of isotopic abundances at least at <u>per mill</u> accuracy and precision. The second instrument, NGMS, is designed for the investigation of planetary gas samples (volatiles, atmospheric gases, composition of exosphere) and allows for measurements with a mass resolution m/Δm ~ 1100 at an extended mass range, which is limited only by the available data acquisition memory. The repetition range of 10 kHz allows for highly sensitive studies with a high effective dynamic range of at least 7 decades.

1. Introduction

Knowledge of the chemical composition is of particular importance to understand the origin and evolution of our solar system. It enables also an insight to major Solar System processes. The measurements of the elemental and isotopic composition with a high sensitivity down to sub-ppm level are of great scientific interest because they can yield detection of all trace species. These in turn gives clue to the evolution of the planetary objects. Among others the mass spectrometric techniques are the most suitable for such investigations because of a high sensitivity of these instruments. The atmospheres of most of the terrestrial planets and some of the outer planets were investigated with mass spectrometry. Mass spectrometry can also be coupled with gas chromatograph (GC) enabling highly sensitive studies of gases trapped in solids. This technique used so far, in laboratories will be now also adopted for space research. Although mass analysis of gaseous samples is relatively easy at present, the mass spectrometric studies of solid materials can be more involved. Nevertheless, a few miniaturised laser ionisation mass analysers were developed during the last decade. The LAZMA instrument has flown on Phobos Return mission and currently is in preparation for Luna Glob and Luna Resurs missions.

We will introduce a miniature time-of-flight mass analysers which can support highly sensitive studies of gaseous and solid samples. While the investigation of gaseous samples can be performed by coupling with electron ionisation ion source, a laser ablation/ionisation source is applied to investigate solid samples. The advantage of using a TOF-MS instead other mass separators stems from their fairly robust and simple mechanical design and a moderate need for resources. High sensitivity of these systems combined with prompt detection of all masses at the same time is also unique property of TOF mass analysers. They offer a high dynamic range and high mass resolution and have the potential to deliver fast quantitative measurements.

1.1 NGMS

We developed a novel time-of-flight mass spectrometer (TOF-MS) for the investigation of gas samples in planetary missions. The instrument support highly sensitive measurements with a detection limit of 2 10^{-16} mbar. With a repetition rate of 1-10 kHz, the measurements conducted during seconds or minutes, a high dynamic range is achieved of about 7 decades. The intrinsic volume of the sensor is less than 1.5 l and weight of 3.5 kg (including margin) and will need about 9 W for full operations. Currently, this instrument is combined with Gas Chromatograph for investigations of lunar volatiles on Luna Glob and Luna Resurs missions [1], [2], [5].

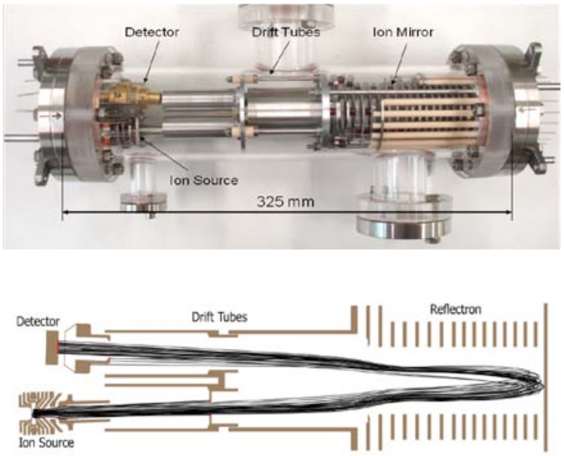

Figure 1. Upper panel shows a NGMS in a glass enclosure and below, a schematic of the instrument with ion trajectories.

1.2 LMS

Our group has designed a self-optimizing miniaturized laser ablation time-of-flight mass spectrometer (LMS) for *in situ* planetary measurements [3]. Our current studies shows that instrument can support high dynamic range of about 10^7 and a typical mass resolution of $m/\Delta m{\sim}700$. A computer-controlled optimizer controls the reproducibility of the performance of the mass analyzer, the laser fluence and the positioning of the sample. The system supports highly sensitive studies of elemental composition with sub-ppm detection limits [4], [5], [6]. Our studies show that high accuracy and precision measurements can also be achieved in the investigations of isotopic patterns. Our initial studies of lead isotopic pattern indicated an accuracy and precision in the per mile range, which are comparable to that achieved by other - well known in isotopic analysis - mass spectrometric techniques, i.e., TIMS, SIMS, LA-ICP-MS used in the laboratory. The space instrument would have a cylindrical shape with a length of 120 mm, and a diameter of 60 mm, and a weight of about 1.5 kg (all electronics included).

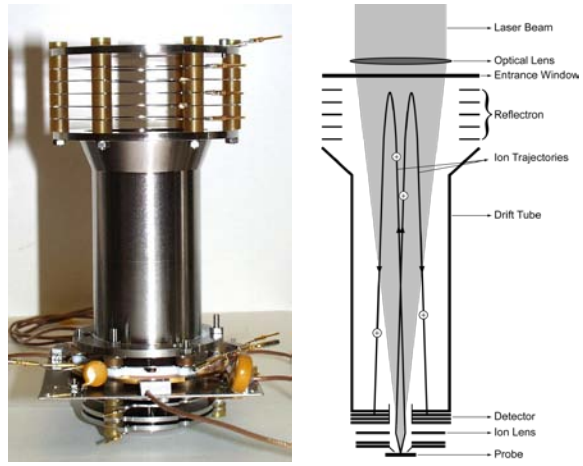

Figure 2. Left panel shows the prototype of LMS and on the right side the construction details and principles underlying operation of the instrument are displayed.

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