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A miniature laser ablation mass spectrometer for in situ elemental and isotopic composition measurements of planetary rocks and soils

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Abstract

A miniature laser ablation mass spectrometer (LMS) is presented. The LMS is designed as a flight instrument for planetary and space research and optimised for in situ measurements of the chemical composition of rocks and soils on a planetary surface. By means of measurements of standard reference materials, minerals and a sample of the Allende meteorite it is demonstrated that LMS is an suitable instrument for in situ measurements of elemental and isotopic composition with high precision and accuracy. Furthermore, it is shown that LMS data allows a derivation of the material mineralogy, petrology with high spatial resolution.

1. Introduction

The chemical composition of planetary bodies, moons, comets and asteroids is a key to understand their origin and evolution [1]. Measurements of the elemental and isotopic composition of a rock yield information about the formation of the planetary body, its evolution and following processes shaping the planetary surface, e.g. volcanic eruptions or space weathering [2]. Therefore, instruments for precise measurements of chemical composition are a key element in every scientific payload on a planetary lander or rover.

From the elemental composition, conclusions about mineralogy and petrology can be drawn. Isotope ratios are a sensitive indicator for past events on the planetary body and yield information about origin and transformation of the matter, back to events that occurred in the early solar system [4]. Finally, measurements of radiogenic isotopes make it possible to carry out analyses of the age of rocks.

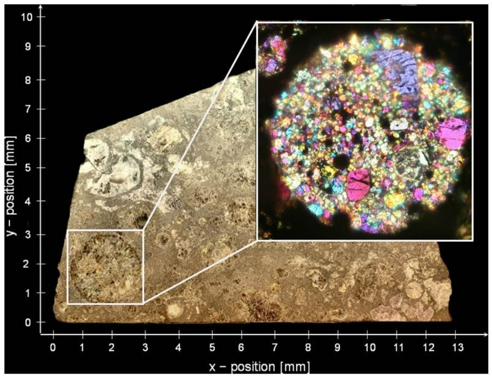
2. Instrumental

The LMS instrument combines a laser ablation/ionisation ion source with a time-of-flight mass analyser. A focused laser beam is pointed on the sample of interest, surface atoms are ablated and ionised. Electric fields guide the produced ions through the ion–optical system on the micro channel plate detector [3]. Measurements in multiple channels with different gain levels assure a high dynamic range allowing the detection of all elements even down to ppb level. Each laser shot results in a full mass spectrum from 0 to 250 amu/q. The laser that is used is a fs–laser in the near infrared with a repetition rate of 1 kHz. Together with the designed data recording and processing chain, this allows for very fast measurements on spots of less than 10 µm in diameter [5].

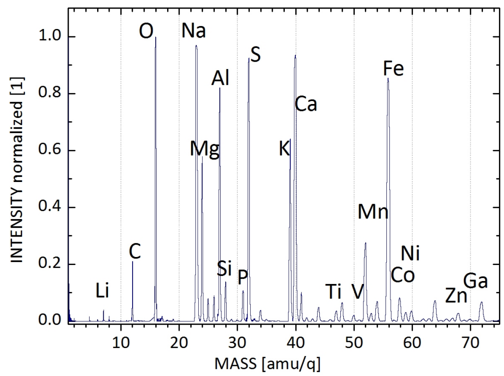
3. Measurements

We carried out measurements on NIST standard reference materials and on terrestrial mineralogical samples like sapphire and other gemstones. For demonstration of the capability of LMS to measure the chemical composition of extraterrestrial material we use a sample of Allende meteorite.

The sample is shown in Fig.1a) with scale in mm. Various features like chondrules and inclusions can be seen. The insert with a magnified view shows one chondrule in tranmitted light. The grains with various mineralogical phases are of few µm size only. Such a single grain with a composition differing from the surrounding material, can comprise very detailed information about global processes of the planetary body or even the early solar system. Fig.1b) shows a part of a mass spectrum from the Allende meteorite, which was gained by summing up the spectra from 60 000 laser shots on one position. The most abundant elements are labeled.



(a)



(b)

Figure 1: The Allende sample that was used in this study shows a large variety of inclusions and chondrules ranging from mm to µm size (a). With LMS the chemical content (elemental and isotopic) of metallic and nonmetallic elements can be measured from 0 to 250 amu/q (b).

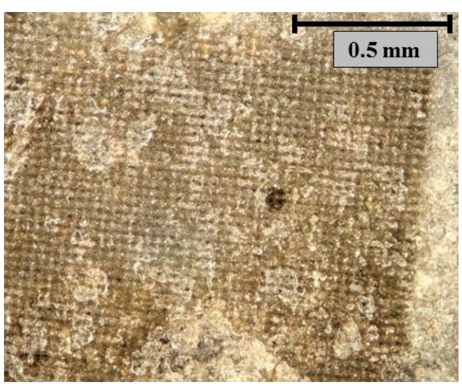


Figure 2: Measurement locations on the Allende meteorite with a spacing of 30 µm between laser spots. Four measurement points are situated on a dark inclusion.

LMS provides the spatial resolution that is needed to gain chemical composition of single grain size spots. As an example, in Fig.2 a region on the Allende meteorite sample is displayed, where a measurement campaign was carried out with 30 µm spacing between individual measurement positions. The sampled region includes a dark inclusion of about 50 µm diameter, which clearly is distinguished by its high Fe, Al and Ca abundance. Only the high spatial resolution allows to distinguish such features from the surrounding meteorite matrix.

4. Summary

We present a miniature laser ablation mass spectrometer for planetary and space research. We demonstrate its performance and powerfulness for in situ measurements of the elemental and isotopic composition of rock samples on a planetary surface. We mark the application possibilities of LMS for petrographic and mineralogical studies, and dating analyses.

Acknowledgments

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