EPSC Abstracts
Vol. 10, EPSC2015-168, 2015
European Planetary Science Congress 2015

A miniature laser ablation mass spectrometer for in situ chemical composition investigation of lunar surface

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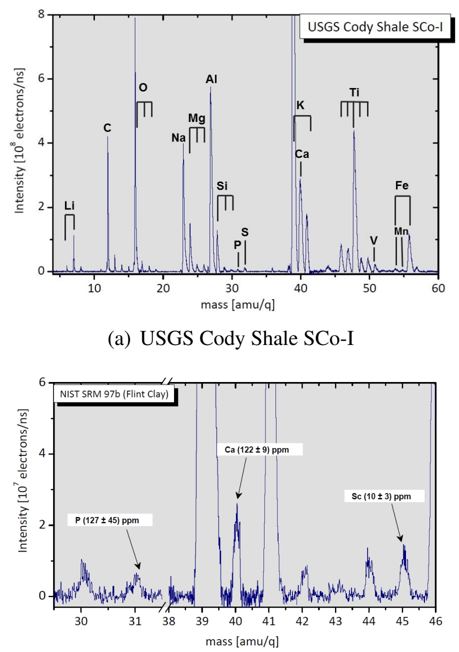
Abstract

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 standard reference materials of soil and a sample of the Allende meteorite we demonstrate that LMS is a suitable instrument for in situ measurements of elemental and isotopic composition with high precision and accuracy. Furthermore, it is shown that LMS data allows deriving of the material mineralogy and petrology with high spatial resolution, lateral and vertical, and the application of in situ age dating methods.

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 [2]. From the elemental composition, conclusions about modal 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. Finally, measurements of radiogenic isotopes make it possible to carry out analyses of the age of rocks. All these topics, particularly in situ dating analyses, quantitative elemental and highly accurate isotopic composition measurements, are top priority scientific questions for future lunar missions. An instrument for precise measurements of chemical composition will be a key element in scientific payloads of future landers or rovers on lunar surface.



(a) USGS Cody Shale SCo-I

(b) NIST 97b Flint Clay

Figure 1: Typical spectra on standard soil samples.

2. Instrument

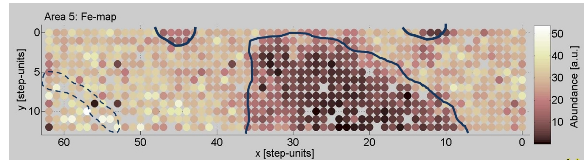
The LMS instrument combines a laser ablation/ionisation ion source with a time-of-flight mass analyser. A focused laser beam is pointed on the sample of interest, surface atoms are ablated and ionised. Electric fields guide the produced ions through the ion–optical system on the micro channel plate detector [3]. Measurements in multiple channels with different gain levels assure a high dynamic range allowing the detection of all elements even down to tens of ppb level [5]. 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 custom-made data recording and processing chain, this allows for very fast measurements on spots of less than 10 µm in diameter [6].

3. Lab Measurements, Preparatory Work

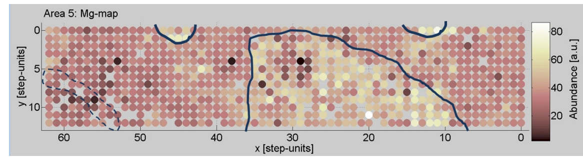
We carried out measurements on a series of soil standards. Measurements of these samples are used to confirm known sensitivity coefficients of the instrument and to prove the power of LMS for quantitative elemental analyses. Fig. 1a) shows the lower end mass scale of a typical spectrum on one of the standard soils (USGS Cody Shale). A few major and minor elements are assigned. Fig. 1b) shows a zoom into a spectrum of the NIST97b (Flint Clay) sample, which demonstrates detection of elements in the low ppm range with high SNR. For demonstration of the capability of LMS to measure the chemical composition of extraterrestrial material we use a sample of Allende meteorite. 4'000 measurements were carried out on the CV3 meteorite, where the measuring plan focused on high spatial resolution with regard to mineralogical analysis of small inclusions and resolution of different regions inside chondrules. Fig. 2 displays the preliminary analysis of one measurement area, where the chemical composition of 680 locations with 50 µm spacing was measured on Allende. Fig. 2a) and b) show the measured relative abundance of Fe and Mg for each single locations. It is noticeable that a certain geometrical feature occurs in both of the maps. Comparing to the optical image of the same region (Fig. 2c), the LMS measurements correctly identifies two different mineral entities separated by the shown contours. Further analysis of such measurements yield detailed information about mineralogy [9]. Investigation of layered samples confirm the high spatial resolution in vertical direction of LMS. It was found that the depth resolution on solid samples is in nm range [8], which allows in situ studying of past surface processes on a planetary surface. Measurements on solid NIST samples focused on the analysis of Pb and application of the ^{207}Pb/^{206}Pb system for age determination. With the measured correlation between isotope abundance and relative accuracy, an estimate was derived for the uncertainty of the radio-isotope chronology. It results that the statistical uncertainty for the age determination by LMS is about $\pm$ 100 Myrs, if abundance of ^{206}Pb and ^{207}Pb is 20ppm and 2ppm respectively. For comparison: in lunar KREEP these Pb isotopes have abundances of tens to hundreds of ppm [7].

Acknowledgments

This work is supported by the Swiss National Science Foundation (SNF).



(a) Fe



(b) Mg

(c) Optical image

Figure 2: LMS measurements of Fe (a) and Mg (b) on a sample of Allende meteorite. The contours found in the element maps agree with a feature also found in the optical image (c) of the same region.

4. Towards Lunar Measurements

We present a miniature laser ablation mass spectrometer for planetary and space research. We established the measurement capabilities of LMS for petrographic and mineralogical analyses, for isotopic studies and dating analyses, which are key topics for future missions to the Moon. Having the LMS instrument installed on a lunar rover would allow to measure the chemical composition of many rock and soil samples, distributed over a certain area, inside the South Pole Aitken Basin for example. LMS measurements would yield valuable conclusions about age and mineralogy.

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