

A LASER-ABLATION MASS SPECTROMETER FOR THE SURFACE OF MERCURY. J. A. Whitby, U. Rohner, W. Benz and P. Wurz, Physikalisches Institut, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland. email: James.Whitby@phim.unibe.ch.

Introduction: The European Space Agency's BepiColombo mission to Mercury is planned to include a lander which will investigate the composition and properties of the surface. The instruments on the lander will both provide 'ground-truth' for the orbiting instrument package, and allow a higher resolution and more detailed analysis of the Hermean regolith. A knowledge of the elemental composition of the mantle of Mercury (which can be inferred from the crust) will rule out some models of how the planet formed as very different predictions are made for the relative proportions of volatile, moderately volatile and refractory elements.

We have developed a laboratory prototype of a mass spectrometer appropriate for this mission which will allow the measurement of both elemental and isotopic compositions with a spatial resolution (lateral and vertical) better than the expected regolith grain size, thus allowing an accurate picture of the modal mineralogy to be built up. The high spatial resolution and the ability to acquire isotopic information will allow the estimated 10% of regolith grains arising from bombardment by chondritic meteorites to be discarded from the data set. Furthermore, depth profiling of individual regolith grains will enable a distinction to be made between the true composition of a mineral grain, and the expected coating of agglutinate materials acquired from micro-impacts.

Advantages of a laser ablation mass-spectrometer over other analytical instruments include sensitivity to almost all elements, high dynamic range, spatially resolved measurements and the determination of isotopic compositions. The mass and power constraints for a Mercury lander are severe, and we expect that an instrument designed for Mercury could be used on other (airless) planetary surfaces with little modification.

Implementation: Following previous suggestions for solid-sampling mass spectrometers intended for *in situ* planetary science [1-3], we selected a laser-ablation time-of-flight system. A pulsed laser is used to ablate the target, and the resulting ion beam is directly coupled to a mass analyser and detection system. Careful control of the irradiance on the target and the beam profile has been shown to minimize elemental fractionation effects in the ablation process [4].

Our initial design was intended to eventually result in a flight instrument with a mass of less than 0.5kg including all electronics. The instrument consists of a

highly optimised axially symmetric reflectron time-of-flight mass spectrometer with the beam from a miniature laser introduced at an angle of 60° to the surface. Using experience gained during the construction of the RTOF mass-spectrometer in the ROSINA package on-board the ROSETTA mission, a laboratory prototype of this design was constructed and is now in routine use allowing us to gain experience with various laser sources and detector configurations, to optimise analytical protocols and to begin calibration studies. Excluding electronics, the entire device has dimensions comparable to a soft-drink can.

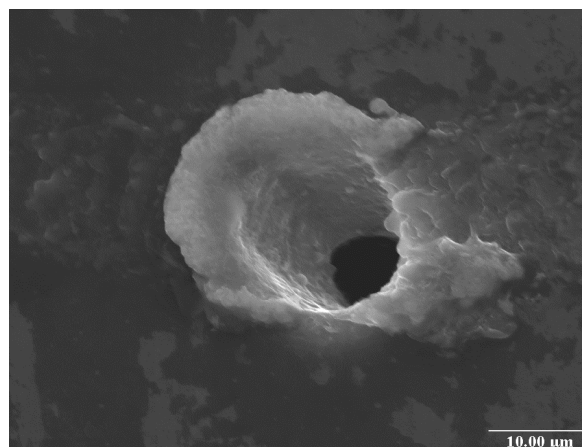


Figure 1 Secondary electron image showing a hole drilled through 60µm aluminium foil using an 11µJ/pulse passively Q-switched 1064nm microchip laser with the laboratory prototype spectrometer and laser optics (single 25mm focal length lens and plane mirror). The elliptical shape is a result of the oblique angle of incidence of the laser beam.

After initial tests using a conventional pulsed electron impact ionisation source, and a laboratory Q-switched Nd:YAG 266nm system, a passively Q-switched microchip laser operating at 1064nm was used for all further work. This laser source was chosen to allow us to gain experience with the technology most likely to be used in a flight instrument. Passively Q-switched microchip lasers are small, robust and efficient and require only simple control electronics and power supplies. Furthermore, their inherently short pulse length, good beam quality and moderate repetition rate make them ideal for this application. However, the constraints on the positioning of focusing

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optics have not allowed us to achieve spot sizes of better than $\sim 15\mu\text{m}$, corresponding to an maximum irradiance on the target of $\sim 7\text{ GWcm}^{-2}$ with the current laser system. We expect to achieve smaller spot sizes, and a greater maximum irradiance when using frequency doubled or quadrupled laser systems. Figure 1 demonstrates the ability of our current laser system to drill through a metal foil.

Performance: Simulations of the performance of the mass analyser using estimated values for the ion energy dispersion have been closely confirmed by experiments. Mass resolution is typically 250 ($M/\Delta M$ FWHM) and the ion transmission efficiency is estimated to be $\sim 3\%$. When using the full pulse energy of the laser ($7.2\mu\text{J}$ on the target), so many ions are produced from some targets that the detector becomes saturated, and so we have not yet been able to fully explore the performance over a range of target irradiances.

Figure 2 shows a mass spectrum obtained from a steel standard consisting of 18.3 wt% Cr, 71.0 wt% Fe and 10.7 wt% Ni. The isotopes are clearly resolved and mass fractionation is minor (less than 30 per mil/amu). A dynamic range of three orders of magnitude is obtained, limited by the averaging having been performed in the 8-bit memory of a digital oscilloscope. Elemental fractionation is however clearly severe in this case. Although part of the chromium enhancement may be due to the surface structure of the steel (a layer rich in chromium oxide is expected) it seems likely that thermal effects are also significant, resulting in the more volatile elements being over-represented. No doubly-charged ions were observed.

Future work: In addition to gaining experience with the laboratory prototype, and assessing the effects of various laser parameters on geologically relevant targets, we have also designed and are building a sub-miniature mass-spectrometer intended to be capable of deployment on a small rover. Utilising a more complex ion-optical configuration this sub-miniature system will fit into a space of approximately $70\times 50\times 50\text{mm}$ (including all instrument specific electronics) and have a mass of 250g. It is hoped that early results from this instrument will be presented at the meeting.

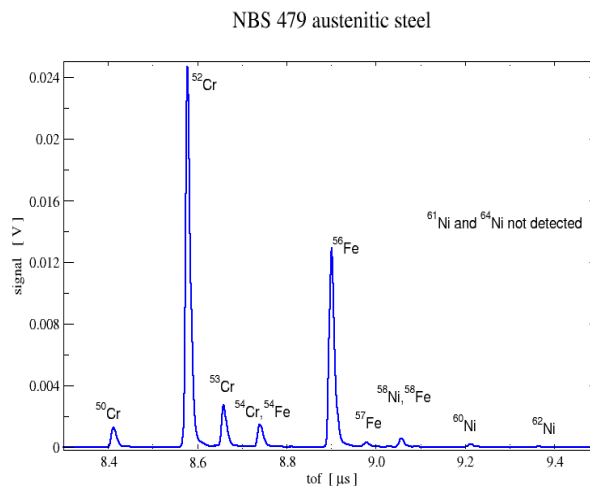


Figure 2 Mass spectrum from steel target, averaged over a few seconds.

References: [1] Managadze G. G. and Shutyaev I. Yu. in *Laser Ionization Mass Analysis* ed. A. Vertes et al., (Wiley, New York, 1993) p.505 [2] Situ W. and De Young R. J. (1995) *Appl. Spectrosc.* 49 791-797. [3] Brinckerhoff W. B. et al. (2000) *Rev. Sci. Instrum.* 71 536-545. [4] Günther D. and Hattendorf B. Chapter 6 in *Laser-Ablation-ICPMS in the Earth Sciences* ed. P. Sylvester, (Mineralogical Association of Canada, 2001, Short Course Series volume 29)