LIBS and Raman Spectroscopy for Planetary in-situ Exploration

K. Rammelkamp (1), S. Schröder (1), U. Böttger (1), S. Frohmann (1), F. Hanke (1), P.B. Hansen (1), S. Kubitza (1), D.S. Vogt (1), and H.-W. Hübers (1,2)
(1) German Aerospace Center, Institute of Optical Sensor Systems, Berlin, Germany (2) Humboldt-Universität zu Berlin, Institute of Physics, Berlin, Germany (kristin.rammelkamp@dlr.de)

Abstract

Laser-induced breakdown spectroscopy (LIBS) and Raman spectroscopy have a high potential for in-situ geochemical and mineralogical analyses for planetary exploration, in particular when combined. These techniques provide complementary information about elemental composition (LIBS) and molecular structure (Raman). The techniques are highly synergetic and can be integrated into one instrument, sharing hardware components such as the laser, spectrometer, and focus mechanisms. The DLR is currently developing a compact and light-weight instrument for application in in-situ robotic exploration of planets, moons, or asteroids where one or both techniques will be applied.

1. Introduction

In general there are strong constraints on the mass, size, and power consumption for rover and lander payload instruments. In the context of the search for habitable environments and extraterrestrial life (a major goal of both NASA and ESA), mission payload instruments for in-situ planetary research must have the ability to do geochemical and mineralogical analyses and, ideally, also be able to detect organics. A combined LIBS and Raman instrument is both capable of realizing these scientific goals as well as meeting the requirements for a compact and lightweight analytical tool. Both techniques are active and use the radiation of a laser to provoke different physical phenomena, leading to specific spectra from a sample of interest and giving complementary information. But also each technique on its own provides interesting insights of extraterrestrial surfaces and an instrument with mass ~1 kg would be a very useful scientific payload for a small pioneering spacecraft.

1.1 LIBS

LIBS is an atomic emission spectroscopy method which permits rapid multi-elemental analysis and relies on ablating material from the sample by focusing a pulsed laser onto its surface. This produces an expanding plasma of atoms, ions, and electrons. The plasma emission is collected and analyzed spectroscopically. With the ChemCam instrument on NASA's Mars Science Laboratory (MSL) mission the LIBS technique was for the first time applied to study the surface of an extraterrestrial body [1-3]. It was shown that LIBS is suitable even with a low-energy laser in ultra-high vacuum environments [4].

1.2 Raman spectroscopy

Raman spectroscopy is a nondestructive method. It is sensitive to the vibrational and rotational states of molecules, and thus can be used for the determination of the mineralogy of geological samples as well as identifying organic and biogenic samples. A small fraction of monochromatic light is inelastically scattered by the substance under investigation, thereby shifting the energy of these exciting photons. The shift relative to the excitation energy is characteristic for the material and provides a unique fingerprint by which the sample material can be identified and its molecular structure determined. Mineralogical, inorganic, organic, or biological compounds can be deduced from Raman spectra by comparing the fingerprint like spectra with a database.

Raman spectrometers are under development for future planetary missions: the RLS instrument for the ESA-Roskosmos ExoMars mission (2020) and a UV Raman spectrometer (SHERLOC) [5] as well as Raman combined with LIBS in the SuperCam instrument [6] both for NASA's Mars 2020 rover. A miniaturized Raman instrument was proposed for instance in [7].

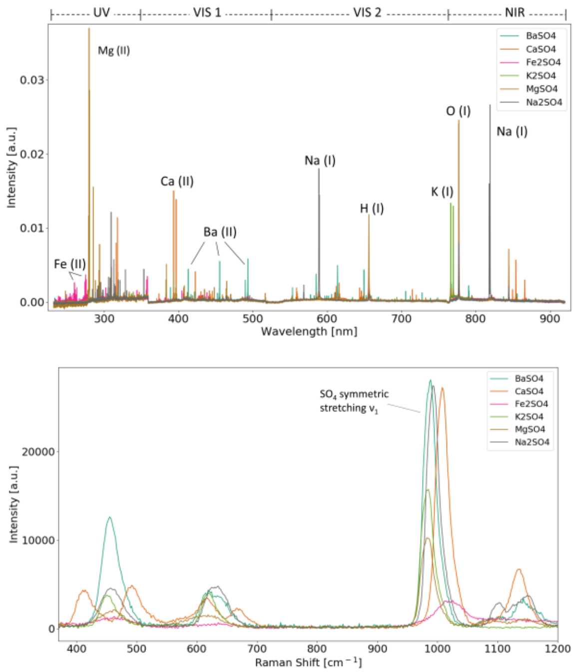

Figure 1, top: LIBS spectra of different sulfates measured with a miniaturized set-up with four spectrometers. Bottom: Raman spectra of sulfates obtained with a miniaturized set-up.

2. Combination of LIBS and Raman spectroscopy

Advantages of combined LIBS and Raman spectroscopy include the capability for high sensitivity mineralogical characterization, high spatial resolution, simultaneous multi-element detection of elements (major, minor, and trace), fast analysis with no sample preparation, and the removal of dust layers. Rock penetration by laser ablation gives information about subsurface material, while with Raman spectroscopy organic compounds can be identified – indicators for possible current or distinct life in subsurface areas. Both techniques have a short acquisition time (seconds/minutes). Furthermore, microscopic as well as remote measurements up to several meters are possible. Remote LIBS-Raman instruments for Mars in particular have been proposed in a number of studies [e.g., 8-10]. The first combined LIBS-Raman instrument SuperCam for remote analysis is currently being developed for NASA's Mars 2020 mission [6].

While the stand-off remote configuration in distances of up to 7 m needs a telescopic system and a powerful laser, a close-up setup with a much more lightweight and compact instrument can also be applied. Such a miniaturized system can be as light as ~3 kg in total, including the laser, the spectrometer and the electronics. As a compact and lightweight instrument it can be mounted on a rover or robotic arm together with complementary instrumentation like a camera. One promising configuration would be a separation of the instrument into a module housed inside the lander or rover (including the optical spectrometer, pump laser and electronics) and one or several optical heads connected with optical fibres. The latter could be part of a robotic arm or get attached, for instance, to the locomotion system of a small rover or crawler.

3. Miniaturization Approach

We report here on the current state of development of a miniaturized LIBS/Raman instrument at DLR. A set-up comprising prototype components is used to test and evaluate different configurations of the instrument for different mission scenarios and their objective. Special focus is on the detection of volatiles and the applicability in vacuum such as encountered on atmosphereless bodies which poses a particular challenge to LIBS.

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