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A miniaturized Raman/LIBS instrument for in-situ investigation of celestial bodies in pioneering missions

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1. Introduction

Different approaches for combined Raman/LIBS (laser-induced breakdown spectroscopy) instruments have been proposed. With SuperCam as part of the Mars2020 mission one will soon be used on another planet for the first time [1,2]. Launching and landing such a large mobile laboratory as the Mars2020 rover with a mass of around 1000 kg is, however, an exception in planetary exploration and most landers and rovers are much smaller.

We propose a miniaturized Raman/LIBS instrument in the order of < 3 kg [3] that could be mounted on a small spacecraft for spectroscopic analysis. The design aims for a lightweight and low power solution with a working distance of up to one meter to keep the advantage of being an in-situ remote science instrument. In the final version the device shall feature an auto-focus mechanism and a close-up context imager.

We report on the current state of development, present data acquired with a prototype model and discuss the capabilities and limits of a miniaturized combined Raman/LIBS instrument. To ensure conclusive results we utilize an atmospheric simulation chamber simulating different planetary atmospheres and vacuum conditions, which strongly influence the LIBS signal [4].

2. Raman spectroscopy

Raman spectroscopy is based on an inelastic scattering process observable in many fluids and solids. The resulting spectra allow for identification of functional molecular groups but also reveal structural differences between minerals of identical chemical composition. For Raman spectroscopy a laser with precisely controlled emission wavelength is desired, as the Raman signal is a relative spectral shift of the incident light. Continuous wave (cw) and pulsed operating mode are both possible. While pulsed lasers in combination with time gated detection enable reliable suppression of fluorescence cw-systems are more robust, easier to handle and less power consumptive. Example spectra of sulphates recorded with the prototype setup are shown in Fig. 1.

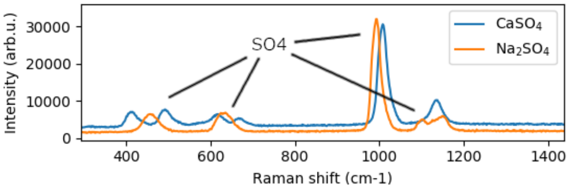

Figure 1: Example Raman spectra of $CaSO_4$ and Na_2SO_4. Both show typical sulphate Raman modes.

3. LIBS

In LIBS a high energy laser pulse is tightly focused onto the sample in order to ablate a small amount of the sample material. The excess energy heats the ablated material and creates a plasma emitting atomic and ionic spectral lines of the elements from the sample and a superimposed continuum from bremsstrahlung and recombination [5]. Excitation above the plasma threshold of ~10 GW/cm^2 is often achieved with nanosecond pulses of a few milliwatts pulse energy provided by q-switched lasers. Fig. 2 shows LIBS spectra of the same sulphates acquired with the prototype components.

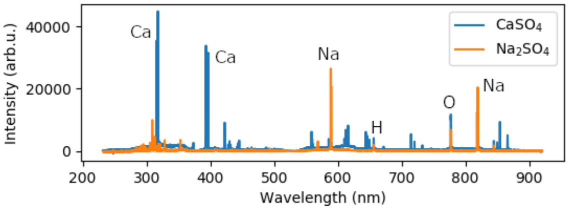

Figure 2: Example LIBS spectra of $CaSO_4$ and Na_2SO_4. Both show the respective cation lines.

4. Combining Raman and LIBS

Raman spectroscopy and LIBS are complementary techniques that work well together in a complete analysis of geological samples [6]. For the example spectra in Fig. 1 the choice of cation introduces a slight shift of the sulphate Raman modes, which can be used for analysis. However, due to other influences on the Raman modes and experimental limitations the unambiguity might not be given. The complementary LIBS spectra in Fig. 2 clearly show atomic and ionic emission lines of either Ca or Na allowing a classification. On the other hand, sulphur is hardly evident in the LIBS spectrum but can be identified via the SO_4 modes in the Raman spectrum.

The experimental setups used for both methods only differ in the laser specifications and the observed spectral range, leaving great potential for miniaturization. With the use of shared components and the intended integration of a high resolution camera the scientific return can be maximized without noticeably increasing the instruments mass. Simple sample preparation tasks such as dust removal can be achieved with the plasma shock wave of a LIBS laser shot exposing a clean rock surface to the Raman system. Due to laser ablation in the LIBS process subsurface layers in depth of up to one millimetre, depending on the material hardness, can be investigated as well.

5. Miniaturization approach

The miniaturized design features a passively q-switched Nd:YLF prototype laser operating at 1053 nm in pulsed mode for LIBS, which was originally developed for ExoMars. It has TRL ~5 and the optically pumped laser head weighs only 36 g [7]. A frequency doubled continuous Nd:YAG laser emitting at 532 nm (1 MHz linewidth, < 3 pm wavelength stability) is used for Raman excitation. Both excitation and detection are co-aligned on one optical axis and share the focusing optics. The collected light is split into four spectral ranges from 240 to 850 nm and delivered to and analysed by four separate miniaturized grating spectrometers. Input from sophisticated data analysis methods and data fusion of LIBS and Raman [8] may reduce the requirements to spectral range and resolution, thus potentially enabling further miniaturization. To focus at various distances a Cassegrain telescope with 50 mm diameter of the primary mirror is considered.

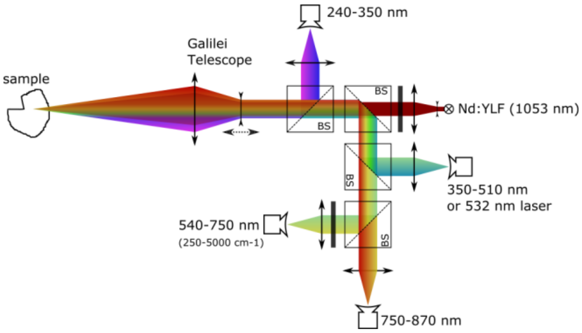

Figure 3: Schematic drawing of the instrument.

6. Summary and Outlook

Combining Raman spectroscopy and LIBS in a miniaturized instrument is a promising approach to equip future missions to explore new planetary bodies, moons and asteroids. With the presented prototype of such a combined instrument elemental components and molecular structures of samples can be identified without sample preparation in small distances around the vehicle. The performance of the system will be evaluated with respect to working distance, laser spot size and focus precision requirements for different potential sample materials. As a next step an auto-focus mechanism and a context imager will be developed and integrated.

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