Characterization Procedure of the Flight Laser Modules for the ExoMars Raman Laser Spectrometer

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Abstract: Several space missions have been sent to the surface of Mars carrying scientific instruments to study the environment. However, only one of these missions included a laser: the ChemCam instrument on-board NASA's Curiosity mission. In 2020, two missions will be launched to study the Martian surface and search for signs of life: NASA's Mars mission carrying SuperCam instrument that will perform Raman spectroscopy and LIBS technique; and ESA's mission, ExoMars, with a Raman Laser Spectrometer (RLS) as part of the rover's payload that will study the Martian surface. One of the critical points of the RLS instrument is the laser, due to the strict technological requirements that must be met to satisfy scientific and environmental requirements. This paper summarizes the electro-optical characterization campaigns that passed the Flight Model (FM) and the Flight model Spare (FS).

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1 INTRODUCTION

The surface of Mars has already been studied for some decades, since the arrival of the first rover in 1997, the NASA's Pathfinder mission rover, Sojourner, being the first probe to touch down on the Martian surface. It was also a NASA mission that took the following rovers to Mars, this time two twin vehicles with the same instruments: Spirit and Opportunity. They landed in opposite regions of the planet in January 2004 with the aim of finding evidence of water on Mars. In 2011, NASA gave up contact with Spirit, and with Opportunity in 2018 (Mann, 2019).

NASA's most recent rover to touch down on Mars is Curiosity, which landed in 2012 and is the only rover still active (Mars Exploration Program, 2019). It is the largest vehicle on the Martian surface and its main objective is to determine if Mars ever had what all life needs: durable water and appropriate chemical ingredients. This rover is still operative and could last longer than the previous ones because it is powered by a nuclear battery instead of solar panels. It was in this mission that the first specific scientific laser for Mars exploration was sent, in the ChemCam instrument on-board Curiosity (Mann, 2019).

The ChemCam instrument used the laser-induced breakdown spectroscopy (LIBS) technique, with a pulsed laser. This laser, about 600g weight, uses three Neodymium-doped Potassium-Gadolinium Tungstate (Nd:KGW) crystals and emits pulses at 1067 nm. It is used to vaporize rock surfaces and soils, creating a plasma of their component gases. The generated plasma is characterized by a spectrometer, included also in ChemCam (NASA Science, 2019). Although in 2018 Curiosity discovered organic materials (Mann, 2019), the LIBS approach does not allow detecting low presence of organic molecules (Ciminelli, Del'Olio & Armensie, 2016).

The ChemCam successor, SuperCam instrument included in next NASA Mars mission, to be launched in 2020, will not only use the LIBS technique but also Raman spectroscopy in a range up to 12m away from the rover. The objective of this mission is to look for signs of past or present life, and to see if humans could one day explore Mars (NASA, 2019). The

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SuperCam laser uses a Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) crystal and emits one laser beam at 1064nm and another one at 532nm (Wiens, Maurice & Perez, 2017). LIBS spectroscopy uses the 1064 nm beam while the 532 nm beam is used for Raman spectroscopy. Mars2020 rover will also include an ultraviolet laser, about 400g weight, to perform proximity Raman with the Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals instrument, SHERLOC, (Beegle et al, 2015).

The next European Martian mission, an astrobiology program by ESA and the Russian space agency Roscosmos, ExoMars mission will be also launched in 2020. In contrast with previous missions, ExoMars will be the first mission capable of moving around the Martian surface while studying the composition of materials at depth thanks to a drill that will extract samples up to 2m below the surface (ESA, 2019). The scientific objectives of the ExoMars mission are: searching for possible biosignatures of past Martian life, characterizing the water and geochemical distribution as a function of depth in the shallow surface to better understand the evolution and habitability of Mars, and achieving incremental steps for future return samples missions (ESA Scientific Exploration, 2019).

ExoMars mission will carry, in its analytical laboratory (ALD), two instruments with laser devices (Vago et al., 2017):

- The Raman Laser Spectrometer (RLS)
- The Mars Organic Molecule Analyser (MOMA)

The goal of MOMA is to seek signs of past life on Mars by analysing a wide range of organic compounds in the collected soil samples, studying large molecules, inorganic minerals and volatile organic molecules using a UV laser. From a Neodymium/chromium-doped YAG (Nd:Cr:YAG) crystal, its 1064 nm beam is converted to its frequency-quadrupled of 266 nm as output beam (Goesmann, et al. 2017).

The other laser on-board ExoMars rover belongs to the RLS instrument, which seeks to search biosignatures and biomarkers on Mars using Raman Spectroscopy (European Space Agency, 2013). This very useful technique is used to identify mineral phases produced by water-related processes. In addition, it will help identify organic compounds and search for microbial life by identifying the mineral products and indicators of biologic activities. RLS will provide geological and mineralogical context information with a non-destructive technique that will allow a cooperative working with the other instruments in ALD, and cross-correlate scientific data (Rull, et al. 2017).

2 RAMAN LASER SPECTROMETER DESCRIPTION

RLS instrument consist of three main units:

- Spectrometer Unit (SPU)
- Internal Optical Head (iOH)
- Instrument Control and Excitation Unit (ICEU)

The Raman Laser Module (RLM) is located in the ICEU, and its excitation signal is carried by means of optical harness (OH#1) to the iOH to illuminate the sample. Another fibre (OH#2) collects the Raman signal to the SPU so it can be processed. These three units, in addition to being connected by optical fibres, are also interconnected by electrical harness (EH) that distributes signal transmission and power supply between them. Some of the main technical characteristics of the instrument are the following (Moral, et al. 2018):

- 2.4 kg of mass
- Work performance in thermal environments between -40ºC and 0ºC, and non-operational survival between -60ºC and +50ºC
- Power consumption between 20W and 30W, depending on the temperature range and operational mode.

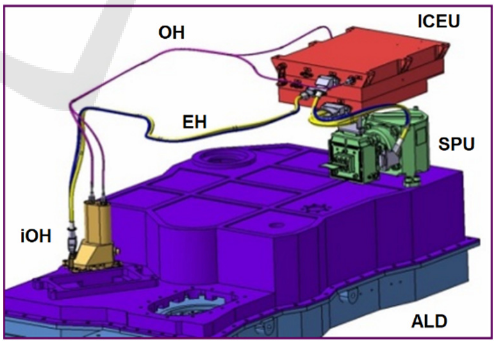

Figure 1: ExoMars Rover ALD with the RLS units layout.

The RLS laser module is one of the most critical parts of the Raman instrument and for its design, scientific requirements and functionalities had to be taken into account. Thus, as top-level scientific requirements for the instrument, the following parameters were taken (Rull, et al. 2011):

- Spectral range of 150 to 3800 cm^{-1}, so that all important spectral bands can be detected in Martian exploration.
- Spectral resolution of at least 6 cm^{-1} (up to 2000 cm^{-1} wave numbers) or 8 cm^{-1} (for wave numbers higher than 2000 cm^{-1}), so that the instrument is able to differentiate between two Raman bands.
- Maximum power on the sample of 0.3 – 0.6 kW/cm^2, depending on the sample: to obtain the highest possible Raman signal without burning the sample.
- Spot size of 50 µm.

2.1 Laser Module Optical Characteristics

According to these requirements, the Raman Laser Module (RLM) was designed and assembled with (Moral et al. 2018):

- Wavelength of 532 nm ± 0.5nm. This is the most suitable for planetary Raman laser spectroscopy because it not only stimulates Raman resonance signals in biomolecules but also has a great performance for geology (Rull & Martínez-Frías, 2006).
- Optical output power from 20 mW to 30 mW. High enough to obtain an adequate signal-to-noise ratio (SNR) in the Raman signal but without burning or altering the sample.
- Redundant laser design. Two lasers channels are included in the unit, as a risk mitigation strategy.
- Main peak stability of ±10pm. The stability of the main peak wavelength is vital to avoid Raman signals disturbed by variations in the wavelength of the emitted signal.
- Main peak linewidth of 29pm, in order to achieve the spectral resolution at instrument level.
- Side mode suppression ratio below -20dB.

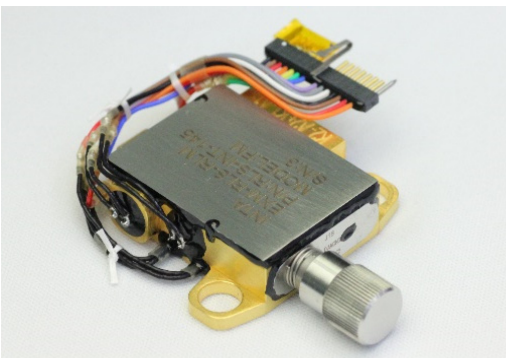

Figure 2: Flight Model of Raman Laser Module.

Both, the spectral behaviour and the level of optical output power are the most important points, and keeping them stable implies a very precise temperature control. Thus, thermal control is one of the critical parameters that must be taken over RLM. The device has two thermal sensors embedded in the module, capable of independently measuring the temperature inside the housing of the laser module. These thermal sensors, together with an external thermo-electric module (TEM) and the associated electronics and software allow a precise control of thermal conditions inside the RLM, necessary to achieve the required spectral stability. The range of working temperatures, or setpoints, admitted by the pumping diodes is 15ºC to 45ºC. However, the operational temperature of the laser module itself was confined between 20ºC and 30ºC, i.e. close to the room temperature used during the optical components alignment procedure. Therefore, electro-optical characterization focused on that temperature interval.

In order to find the exact working points for each laser contained inside the RLM, LD1 and LD2, it is necessary to know the optical behaviour of each one in a temperature range around 25ºC, as well as in a feeding current range between current threshold and the maximum current provided by the flight laser driver, that are 0.5A and 1.5A, respectively. It is not only important to characterize the behaviour of the main peak at 532 nm: the pumping laser diode (PLD) wavelength is also useful for monitoring purposes. Even though, by design, the externally available PLD output power is very low, its spectral contribution could still be distinguished with a high enough SNR. The PLD emission wavelength, close to 808 nm, is directly related to the device temperature. Monitoring the PLD wavelength while changing the temperature and feeding current setpoints, for LD1 and for LD2, will facilitate us to check the thermal operation of the RLM, and later correlate these measurements with those obtained after the RLM integration into the ICEU.

These critical parameters were the main ones to cope with in the characterization campaigns of the flight models. Specific tests were designed to fulfil these functional characteristics and the requirements imposed on the RLS instrument.

3 FLIGHT MODEL OPTICAL TEST CAMPAIGN

The RLM Flight Model (FM) characterization campaign consisted on a series of tests designed to characterize and evaluate the behaviour of the selected device, aimed to select the working points that met the requirements. In particular, the strategy of the Raman laser flight model characterization campaign comprised two main steps:

- Gross output power and spectral performance assessment over a wide temperature and current range. This first step is performed to estimate one or several potential setpoints within each laser unit.
- Fine output power and spectral performance assessment in the proximity of the candidate setpoints in order to confirm its feasibility and check the performance stability at the selected setpoint.

3.1 Characterization Results

The goal of this global search is to pick up a starting temperature and current setpoint for a detailed assessment of laser performances. For that, a test was carried out by sweeping in temperature (from 22.5ºC to 27.5ºC) and currents (from 0.5A to 1.5A), and recording in each step both output power and spectrum using a beamsplitter (BS) fibre. As an example, optical output power values and spectrum are represented in Figure 3 and Figure 4, respectively.

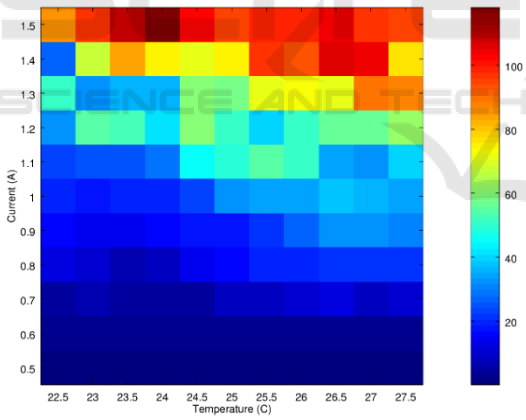

Figure 3: Optical output power (mW) 2D map from RLM FM LD1.

From these figures, we can identify the potential setpoints, those temperature-current areas where the optical power value is between 20 - 30 mW and the secondary peak is below -20dB (Figure 5).

The spectral range recorded is 400 nm to 1100 nm, so Nd:YAG peak at 1064 nm and PLD wavelength at 808 nm can be assessed. PLD wavelength variations due to temperature and current in the test carried out are relevant (Figure 6), and therefore PLD peak information is also reported during our automated tests (Figure 7).

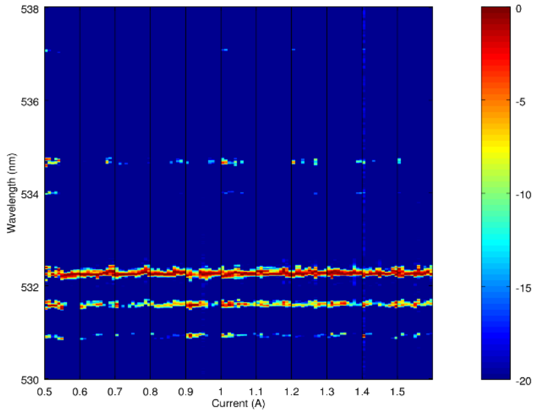

Figure 4: Spectral performance close to 532nm in normalized power density (dB/nm) from RLM FM LD1.

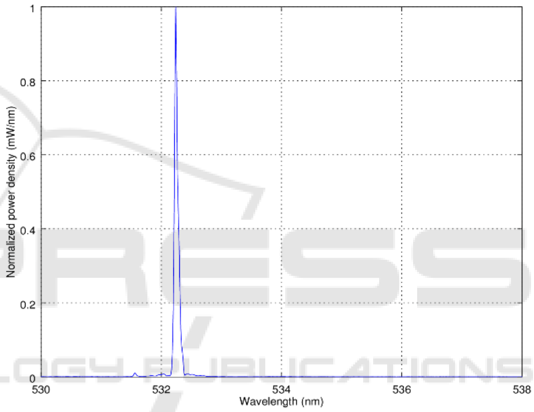

Figure 5: Spectrum centred in 532 nm from RLM FM LD1, in the selected setpoint.

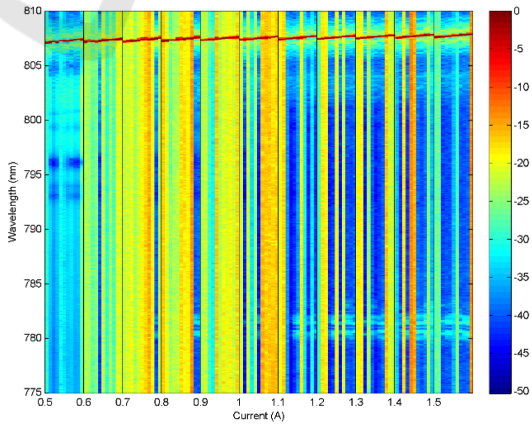

Figure 6: Spectral performance close to PLD wavelength in normalized power density (dB/nm) from RLM FM LD1.

This test was repeated in the same temperature and current ranges, but recording only optical power,

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in order to obtain LIV (power, current and voltage) curves.

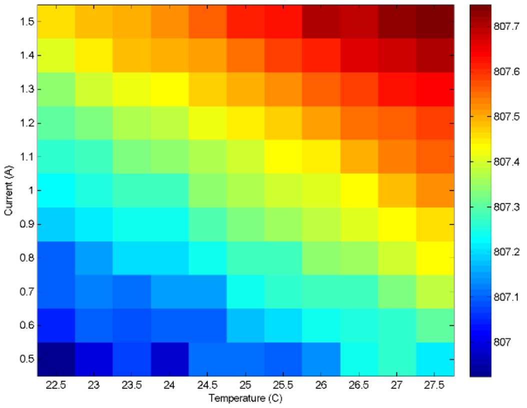

Figure 7: PLD peak wavelength (nm) 2D map from RLM FM LD1.

3.2 Stability Results

After pre-selecting the potential setpoints, a fine characterization is made around them and stability measurements are taken. For that, each laser is switched on at its setpoint and optical output power (Figure 8) and spectrum (Figure 9) are recorded.

4 FLIGHT SPARE OPTICAL TEST CAMPAIGN

For the Flight Spare model (FS), the campaign followed the same strategy as in the FM, with the aim of finding the working setpoints that met the spectral requirements as well as the optical power and stability.

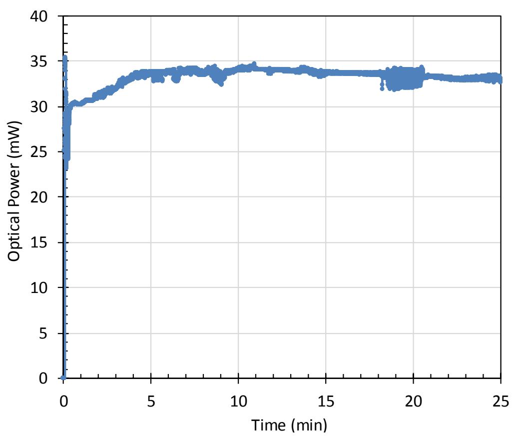

Figure 8: Optical output power stability measurements RLM FM LD1.

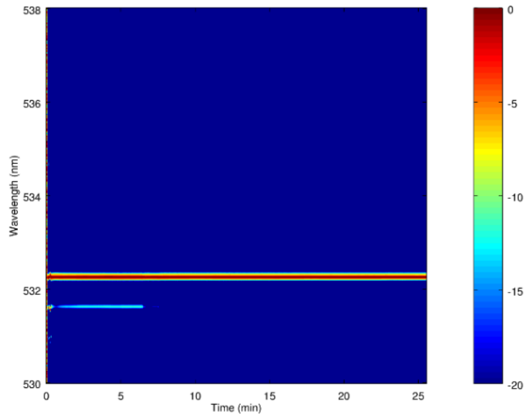

Figure 9: Spectral performance stability close to main peak from RLM FM LD1, in normalized power density (dB/nm).

4.1 Characterization Results

An extended characterization RLM FS was performed sweeping in temperatures (from 22.5ºC to 27.5ºC) and feeding currents (from 0.5A to 1.5A). Optical power was recorded in every temperature-current setpoint, as well as feedback photodiode values. After that, this test was repeated saving both optical power and spectrum by means of a beam-splitter.

An example of spectrum performance from RLM FS LD2 characterization can be seen in Figure 10. These values, combined with the ones obtained in optical power performances (Figure 11), give us the key to select an appropriate setpoint.

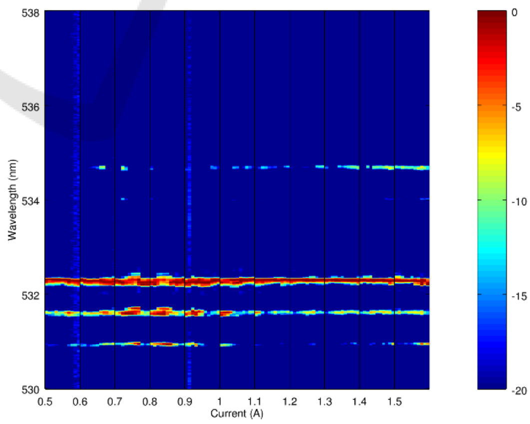

Figure 10: Spectral performance close to 532nm in normalized power density (dB/nm) from RLM FS LD2.

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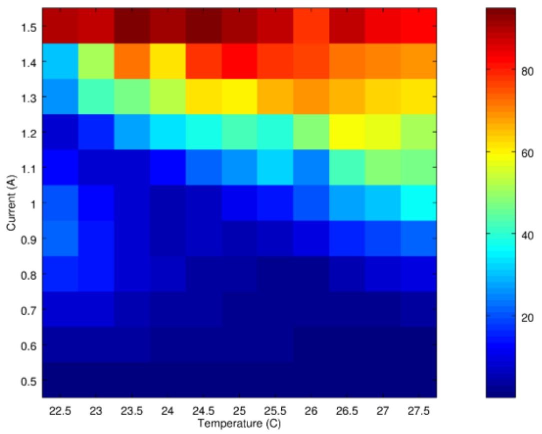

Figure 11: Optical output power (mW) 2D map from RLM FS LD2, estimated from beamsplitter.

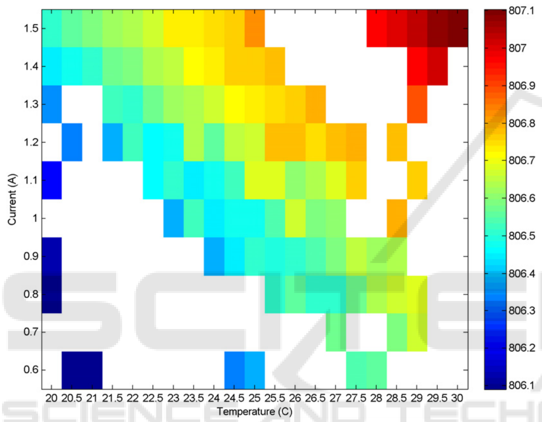

Figure 12: PLD peak wavelength (nm) 2D map from RLM FS LD2. Blank data correspond to low SNR spectral signal at PLD emission wavelength.

The characterization test was repeated, but this time from 20ºC to 30ºC to explore a wider temperature range. Figure 12 represents PLD peak wavelength from the recorded spectra. White areas are due to improper Gaussian fitting in the calculation of PLD peak position due to a low SNR. Expressions relating the PLD peak wavelength with the temperature and feeding current are calculated from the represented values.

4.2 Stability Results

In the same way as in the FM characterization campaign, once a preliminary setpoint was selected, the repeatability of the performance of both LDs was checked, as well as stability behaviour (Figure 13).

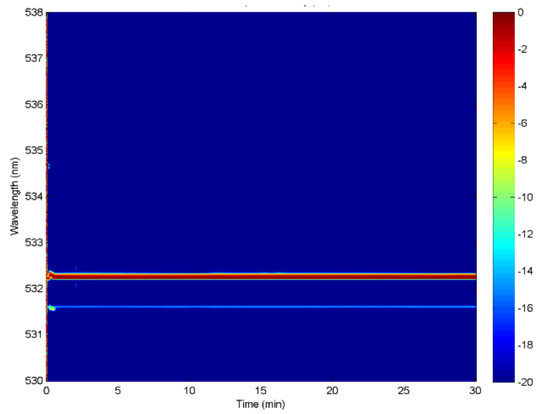

Figure 13: Spectral performance stability close to main peak from RLM FS LD2, in normalized power density (dB/nm).

5 CONCLUSIONS

The characterization campaigns of the Raman instrument's laser flight models comprised a series of tests dedicated to identify the working points where the laser complied with the required performances. For this purpose, an optical and spectral characterization was performed, making a sweep in temperature and current to identify the areas in which each laser could give the necessary optical power and an adequate spectral behaviour. In addition, once the setpoints had been selected, additional measurements were performed to assess the spectral and power performance stability over the foreseen Raman measurement time.

With these tests, it was possible to obtain a detailed record of the behaviour of flight models in a wide range of temperatures and currents, as well as to determine the appropriate working setpoints to meet the requirements for both lasers in each Raman Laser Module.

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