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Transmission grating Validation and Qualification for Mars and Future Planetary exploration Missions

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Abstract

In the frame of ExoMars 2018 mission (ESA-Roscosmos collaboration), the Instituto Nacional de Técnica Aeroespacial (INTA) in Spain, has successfully finish validation test plan of the transmission grating, one of the key optical components that forms part of the Spectrometer Unit of the instrument Raman Laser Spectrometrer that will be on board of ExoMars 2018 and that has never being qualified before

1. ExoMars Programme introduction and objectives

ExoMars 2018 mission is an ESA-Roscosmos collaboration and will deliver a European rover and a Russian surface platform to the surface of Mars. The ExoMars rover will search for signs of life. It will collect samples with a drill that is designed to extract samples from various depths. Once collected, it is delivered to the rover's analytical laboratory, which will perform mineralogical and chemistry determination investigations.

Establishing if life ever existed on Mars is one of the outstanding scientific questions of our time.

The main science objectives of the ExoMars mission can be summarized as:

- To search for signs of past and present life on Mars.
- To characterize the water/geochemical environment as a function of depth in the shallow subsurface;
- To study the surface environment and identify hazards to future human missions;
- To investigate the planet's subsurface and deep interior to better understand the evolution and habitability of Mars.

In term of mission strategy, and in order to achieve the above scientific objectives, ExoMars must demonstrate, between others, the technology of Automatic sample preparation and distribution for analyses with scientific instruments.

To address these exobiological and geochemical issues, Raman Spectroscopy technique has been selected through to Raman Laser Spectrometer Instrument (RLS) that forms part of an Analytical laboratory instruments in the body of the vehicle. The Rover subsurface sampling device will drill down to maximum 2 m. The sample will be crushed into a fine powder. By means of a dosing station the powder will then be presented to RLS and other instruments.

2. Raman Spectroscopy Technique

Raman Spectroscopy is used to analyse the vibrational modes of a substance either in the solid, liquid or gas state. It relies on the inelastic scattering (Raman Scattering) of monochromatic light produced by atoms and molecules. The radiation-matter interaction results in the energy of the exciting photons to be shifted up or down. The shift in energy appears as a spectral distribution and therefore provides an unique fingerprint by which the substances can be identified and structurally analyzed.

Therefore, by analysis of Raman spectral pattern and detailed peak positions, phase identification and chemical characterisation can be made.

Raman Spectroscopy uses a monochromatic light which produces vibrational states in the material whose emission is related to the **molecular composition** of the sample.

It is a well recognized **non-destructive analytical tool**. The shift in energy appears as a spectral distribution and therefore provides an **unique fingerprint** by which the **substances can be identified and structurally analyzed**.

3. Raman Laser Spectrometer Instrument

One of the key rover´s laboratory instruments is the Raman Laser Spectrometer (RLS) which capabilities and objectives are in the line of ExoMars ones. RLS is able to characterize mineral phases produced by water-related processes, to characterise water/geochemical environment as a function of depth in the shallow subsurface, to identify the mineral products and indicators of biologic activities and to identify organic compound and search for life. RLS is based on Raman spectroscopy technique that provides a fingerprint by which the molecule can be identified.

The **RLS working flow** is depicted in Figure1; the powdered sample will be illuminated by means of the iOH optics, with the laser light coming (through the excitation fiber) from the pump diode housed at the ICEU. The Raman signal obtained will be properly filtered and delivered by the iOH (through the reception fiber) to the SPU. At the SPU the Raman signal will be sent through the transmission diffraction grating to the CCD. Image obtained will be sent to the ICEU FEE (Front End Electronics), and processed by the processor electronics, previous to be sent to the Rover.

It is important to remark that in parallel to the design, RLS team works on improving its **Technological Readiness Level**, which is a challenge objective also while mission or requirements are changing.

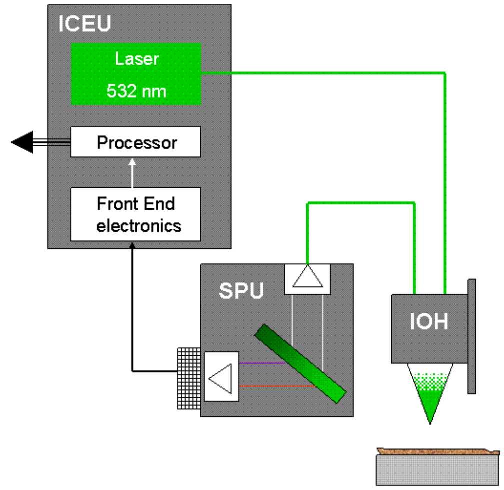

Figure 1: RLS functional Flow.

4. Spectrometer Unit

One of the most critical Units of the RLS instrument is the Spectrometer Unit (SPU) that performs spectroscopy technique and operates in a very demanding environment (radiation, temperature, dust, etc.) with very restrictive design constraints (mass, power, schedule). It is a very small optical instrument capable to cope with 0.12 – 0.15 nm/pixel of spectral resolution and withstand with the Martian environment (operative temperature conditions: from -40ºC to 0ºC (6ºC for CCD)). The solution selected is based on a single transmisive holographic grating especially designed to actuate as the dispersion element.

In parallel to the SPU FM design, a set of activities have been performed by SPU Team in order to achieve the Technology Readiness level 5 (TRL5) for PDR as the Grating validation test campaign which is the objective of this abstract.

4.1. SPU Flight Model Optical Design

SPU Optical design (Figure 2) has been performed by INTA Optical Engineering (Spain).

As explained before, the design of a spectrometer unit that withstand with the Martian environment is a **very demanding optical effort**. The very small optical instrument required can be based on a single **transmisive holographic grating** especially designed to actuate as the dispersion element that separates the spectral lines in one row on the detector.

Efficiency up to 70% at the whole spectral range (533-676nm).The selection of glasses is also of vital importance to assure the behaviour of the instrument in the operative thermal range.

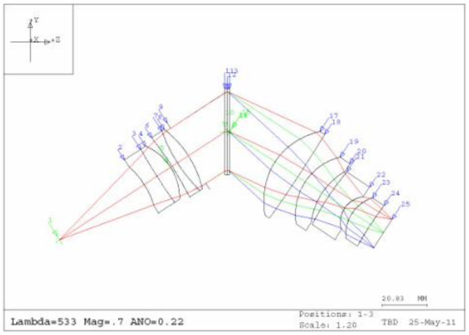

Figure 2: SPU Optical Design.

The SPU Optical subsystems have been then designed attending to their main functionalities. These S/S's are the collimator, the dispersive element and the collector, and the main element is the diffraction grating that separates the spectral lines in one row on the detector.

The VPH (Volume Phase Holographic) grating, supplied by Wasatch Photonics, is recorded on dichromated gelatine. Fig. 3 shows a front and side view of this kind of gratings.

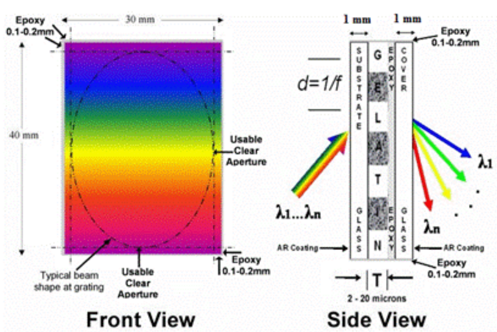

Figure 3: Example of a VPH grating from Wasatch Photonics.

4.2. SPU FM Transmission grating

The transmission grating disperses spectrally the flux produced by the collimator subsystem. It is a Volume Phase Holographic Grating from Wasatch Photonics, working at the same Angle Of Incidence (AOI) and Diffraction (AOD), 32.84°, and with efficiency up to 70% at the whole spectral range (533-676nm).

The Volume Phase Holographic grating is recorded on dichromated gelatin (DCG), which is typically 2-20 microns thick, placed between two pieces of glass (fused silica) like a sandwich. The epoxy used to sealing the VPHG is NOA61. The type of sealing used is the named "O" ring seal which consist of removing some of the gelatin, 3mm, from around the grating. This reduces the clear aperture of the grating but is more robust sealing.

The VPHG physical size is 38x44mm with an active area (clear aperture) of 30x36mm.

5. SPU transmission grating Technology Level

At SPU component level, it has been identified all the technological risk areas of the unit and established their mitigation plans. All SPU components that are not available as space qualified devices or without enough space heritage or which have not been qualified for the same space environment (temperature, vibration, radiation, etc.), have been included as technological risk devices. All COTS are also included in this group and the same applies to material, parts and processes.

The diffraction grating is a COTS and so it was identified in the beginning of the project as a potential technological risk. In order to mitigate this risk, a dedicated plan was created and this Validation Plan has been elaborated as a previous stage of SPU flight model design.

The validation campaign was performed from January 2010 to January 2013. For the validation test, two different specimens were evaluated: DCG samples and the diffraction gratings VPHG. DCG samples are structurally identical to VPHGs, but on the samples there is no grating recorded: between two fused silica glasses it is placed dichromated gelatine (DCG) and the set is sealed with the same adhesive that the VPHG. The objective of analysing the DCG samples is to allow identifying which component, gelatine, glass or adhesive, of the grating is affected by ExoMars conditions.

Gratings and samples were tested under ExoMars conditions, and they were characterized optically before and after each test. Comparing the optical performances of the gratings and samples of both measurements (before and after), we could observe any degradation suffered by the gratings due to the exposure of mission conditions.

For the gratings, the optical measurements done are diffraction efficiency, angular selectivity and centred peaks. For the DCG samples, the measurements are transmission, reflectance, and complex refractive index.

In the frame of this Validation plan there were four different lines for the tests to be performed. Each line was composed by three VPHGs and two samples, with the exception of the proton irradiation, where only one sample is used.

Test performed that has been successfully carried out:

- Non Operative Thermal Vacuum test.
- Operative Thermal test.
- Mechanical test.
- Gamma and Protons Irradiation test.
- UV Irradiation test.
- Sealing test.

6. Summary and Conclusions

The diffraction grating is the key optical element of the Spectrometer Unit of the RLS Instrument and as it is a COTS, a complete Validation test plan has been performed as a previous stage of a qualification campaign.

Test plan has been successfully complete before the PDR so SPU team is confident about the grating optical behavior under space conditions.

Currently Grating Qualification test plan is already prepared but there is only one difference between the gratings procured for Validation Test Plan and the ones procured for Qualification Plan and flight units: the size, so it could be conclude that the Gratings will be successfully qualified.

Finally it is important to remark that although the validation of the gratings came from the need of ExoMars 2018 program, as during the cruise phase and also in Mars, the environment is very strict, it could be said that **in INTA it has enabled a new technology for Planetary science and exploration**.

Acknowledgements

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