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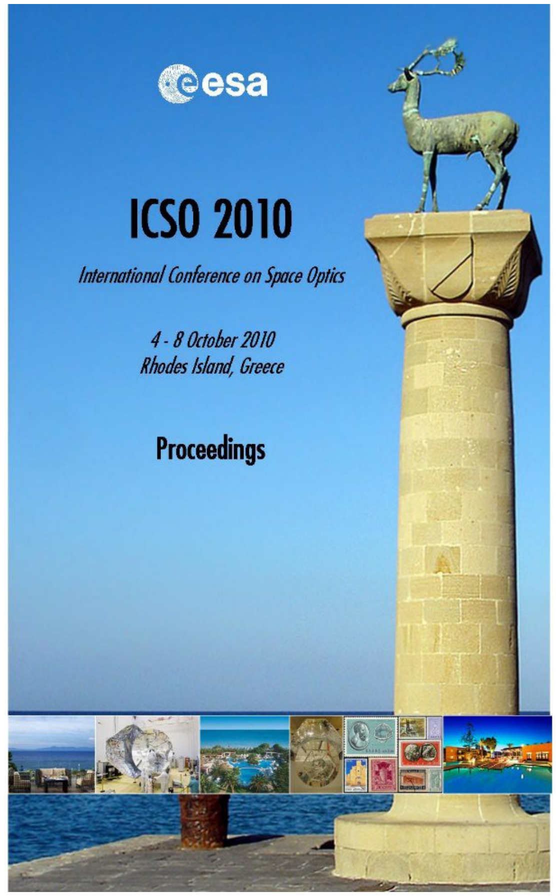

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INNOVATIVE OPTICAL TECHNIQUES USED IN THE RAMAN INSTRUMENT FOR EXOMARS

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I. INTRODUCTION

The optical part of the Raman Laser Spectrometer (RLS) instrument for ExoMars consists of an excitation laser, an optical harness, an optical head and a spectrometre. The optical harness delivers the green radiation generated by the laser to the optical head which, in turn, focuses the laser radiation on the sample of interest and collects the Raman emission from the sample. The optical head then separates excitation light and Raman emission by a filter setup and sends the isolated Raman signal to a reception fiber, which delivers it to the spectrometer of the instrument. This paper concentrates on the innovative technologies applied for the excitation path of the instrument, the laser, the optical harness with its new compact fiber optic connectors and the Raman optical head; and describes their design, the design driving requirements and the status these units have reached by now. The spectrometer of the system with its transmission grating design will be presented separately.

II. LASER

Given the very stringent requirements of the mission, the laser is bound to several key constraints: small weight and size, low power consumption, robustness, radiation resistance, compliance with planetary protection and high temperature range (to name a few). The design of the Diode Pumped Solid State Laser (DPSSL) has been changing throughout the development of the project but at the present stage it has already addressed most of the issues (see Fig.): it weighs less than 40grs and occupies around 7cm^3; it is higly efficient, being able to deliver 300mW of green light with about 4W of electrical input; and it has an operating temperature of around 40ºC. The large operational temperature range is provided by the wavelength-stabilised laser diodes used for the infrared pumping and the careful choice of laser and Second Harmonic Generator (SHG) crystals. Redundancy is implemented inside the housing of the laser with two independent laser cavities. It is also equipped with a monitor photodiode feeding a feedback loop which allows the stabilization of the output power and a photodiode for the autofocus of the instrument described below. The key materials of the laser have already been validated to mission-level gamma and energetic proton radiation.

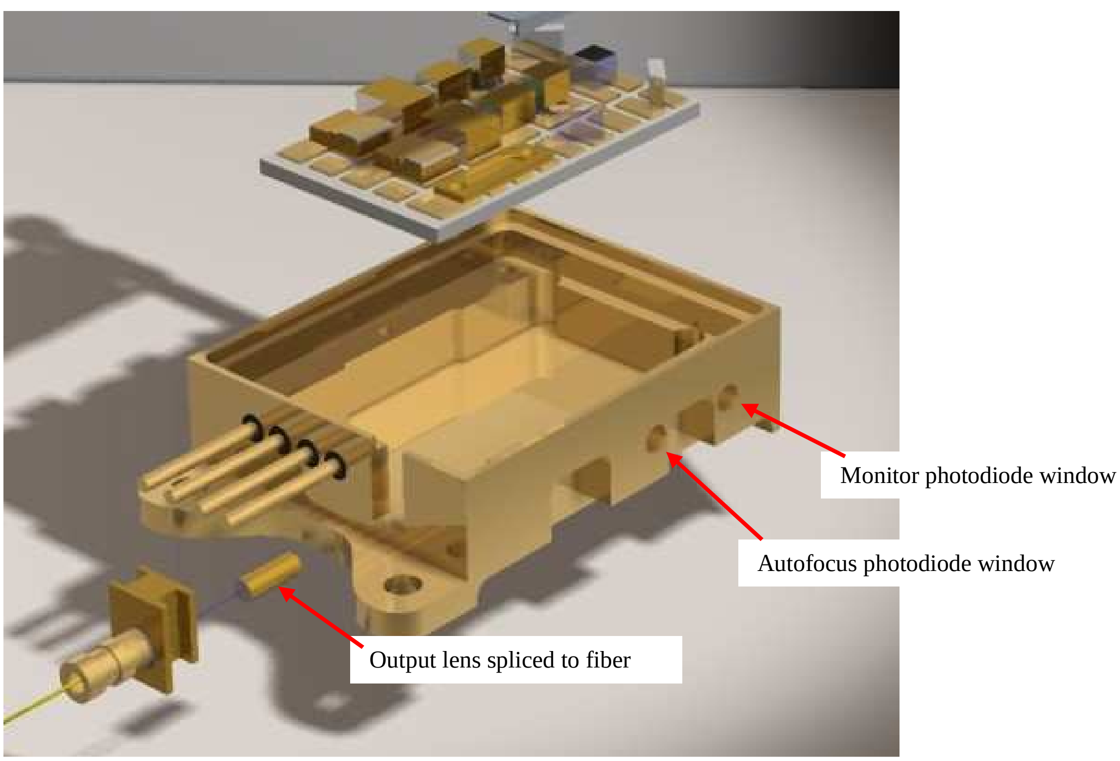

Fig.1, Outline of the laser housing with its optical interfaces

In addition to this, two innovative technologies developed in the Fraunhofer Insititute (IOF) are being studied as potential candidates to improve the performance and the robustness of the laser. On the one hand, there is the "splicing" of the optic fibre and the output lense which guarantees no change of refraction index. On the other, there is the "solderjet bumping" technology, originally conceived for electronics[1] and presently being implemented to allow soldering of optical components by the Fraunhofer Institute. This method consists on the projection of small spheres of soldering material which allows the bonding of the metal-coated optical component to the base while asserting a very small thermal impact to its structure. It would provide a very strong bonding of the components and avoid the use of potentially outgassing bonders.

Other measures are being considered to reduce potential misalignements and stresses due to temperature fluctuations and vibrations, such as the use of an AlN baseplate to minimise the CTE missmatch between optical components and the baseplate itself and the use of a flexing internal mount to keep the baseplate steady while absorbing the vibrations.

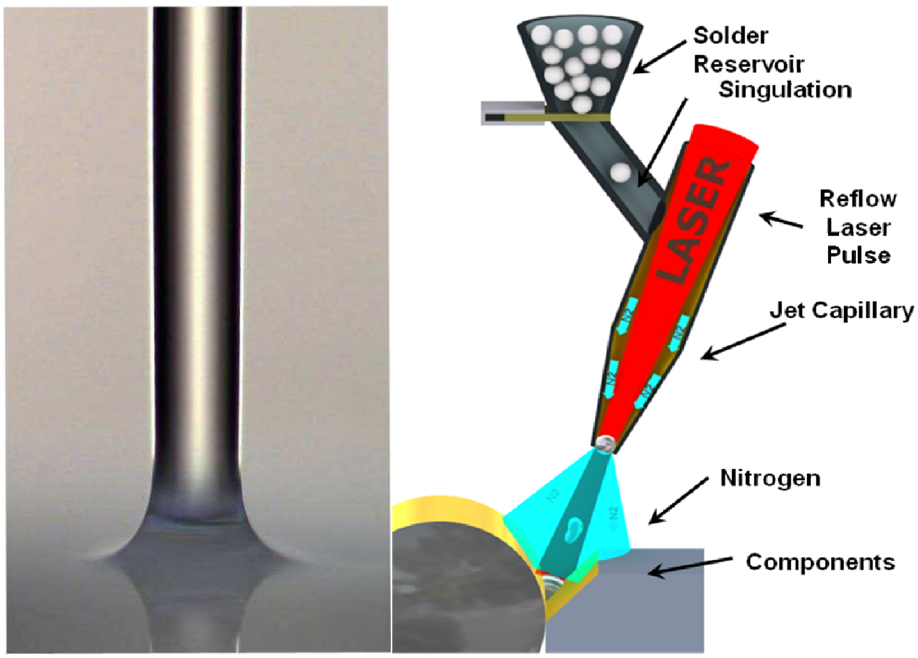

Fig. 2, Example of the splicing technique (left) and diagramme of the solderjet bumping mechanism (right) from the Fraunhofer Institute.

III. OPTICAL HARNESS

For the optical harness (excitation and reception path), multimode step-index fibers with a core diameter of 50µm are used. The fibers have a depressed fluoride-cladding and a polyimide coating. Several evaluation tests were performed at the beginning of the project to select the proper fiber type, including radiation and thermal tests. The results of the radiation tests are presented in [1]. The fiber has an increased hydroxide (OH) content, which reduces the radiation induced attenuation but on the other hand has an absorption band at about 1300nm (which is negligible for the instruments operation wavelength range between 500nm and 800nm). The fiber cable is a Gore 1.2mm Simplex spaceflight cable.

As mass budgets are extremely limited for the instrument, a light-weight small form factor fiber optic connector is desired. For years, the Diamond AVIM connector has proven to be a high reliable connector for spaceflight applications. The same performance was requested for a new small form factor connector. Within the framework of this instrument's development activity, Kayser-Threde initiated a connector development at Diamond, which was intended to combine some features of the robust AVIM connector with the small size and mass of the DMI connector. The result of this development is the new Diamond MiniAVIM connector (see Fig. 3).

[1] Patented by PachTech

Fig. 3, Comparison of the AVIM (top) and MiniAVIM (bottom) connector

The large advantage of the MiniAVIM is the very low weight: a connector set consisting of two connectors and a mating adapter weighs less than 5 grams (compared to the 20 grams of an AVIM connector set). The MiniAVIM showed similar performance during thermal and vibration tests to the AVIM connector [2]. Further evaluation and flight qualification tests will be performed within the ExoMars project.

III. OPTICAL HEAD

A fiber coupled optical head focuses the excitation laser light onto the sample to be investigated and images the Raman response towards the second connected reception fiber. To achieve a most compact and light weight design, the optical system images the 50µm fibers to a 50µm spot on the sample (magnification = 1) and vice-versa.
The backscattered Rayleigh light of the sample is used for focusing purposes. The integrated robust filter setup, consisting of a laser line pass filter and three extremely steep Raman long wavepass filters, allows in-situ blocking of the unwanted Raman signature of the excitation fiber and suppression of the Rayleigh backscattering signal for the excitation path up to an optical density of >10-12; essential for Raman detection at low wavenumbers, close to the excitation laser line (see Fig. 4).

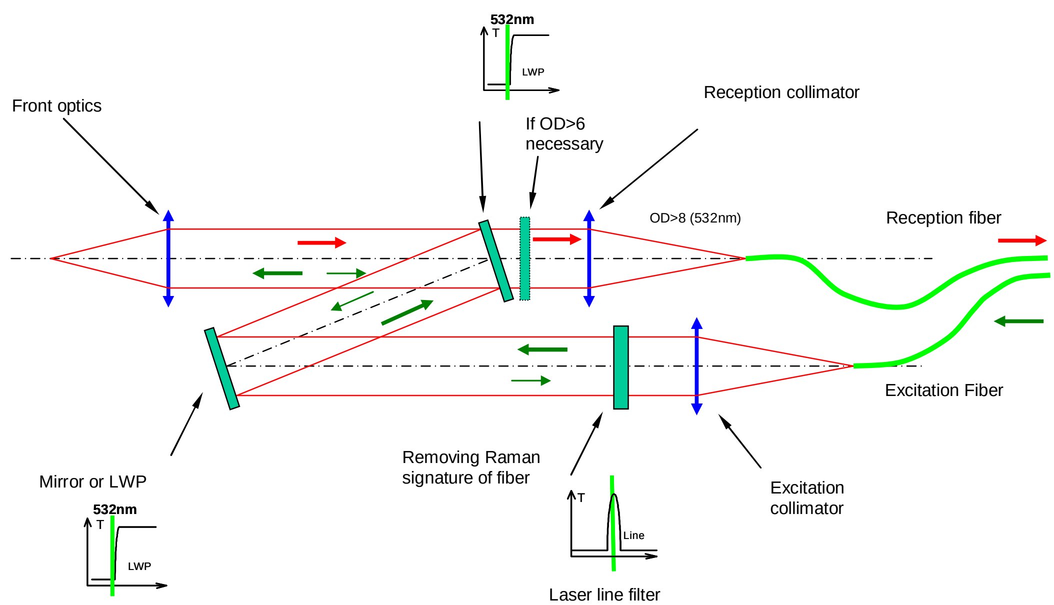

Fig. 4, Filter concept of the optical head for removing fiber and Laser signatures in the excitation path and for blocking the backscattered excitation wavelength in the reception path

To cover the extreme thermal range required (-150°C to +125°C non operating and -60°C up to 30°C), the optical head is designed with all-aluminum reflective optics. The optical head consists of an aluminum optical bench for mounting and aligning of two very small parabolic fiber collimators, the complete Raman filter setup and the so-called front optic (see Fig.5). The Raman interference filters are custom designed, coated on low-autofluorescence fused silica substrats and mounted thermally compensated on the optical bench. The front optics are basically a classical on-axis infinity corrected Schwarzschild two-mirror optics (spherical only) which allows focusing the collimated excitation and reception beam paths to the sample with a sufficiently high required backfocal distance.

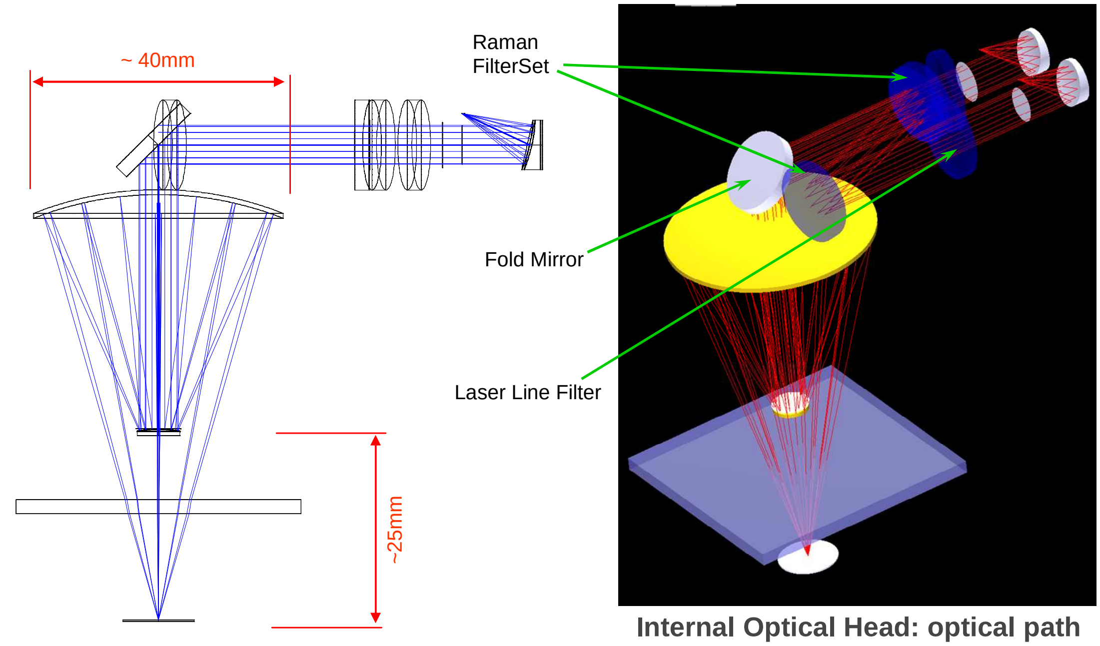

Fig. 5, Optical layout for achieving the high back focal distance

The central obscuration of the on-axis Schwarzschild design causes throughput reduction. By generating higher order modes in the fiber (ring mode) this effect can be circumvented.
All aluminum mirrors are manufactured by single point diamond turning of a very fine-grain RSA6061 meltspinning aluminum (RSP Technology, NL) without any need of additional polishing. An enhanced protection coating of the mirrors provides a significantly higher reflectance in the observed wavelength range, between 532-700nm, than that of bare aluminum without disturbing the thermal behavior of the aluminum mirrors.

The complete optical head, as shown in Fig. 6, has been tested at extreme thermal-vacuum and mechanical loads without degradation in performance. The measured change of coincidence of the focus spots of both excitation and reception paths was in the order of about 1µm only.

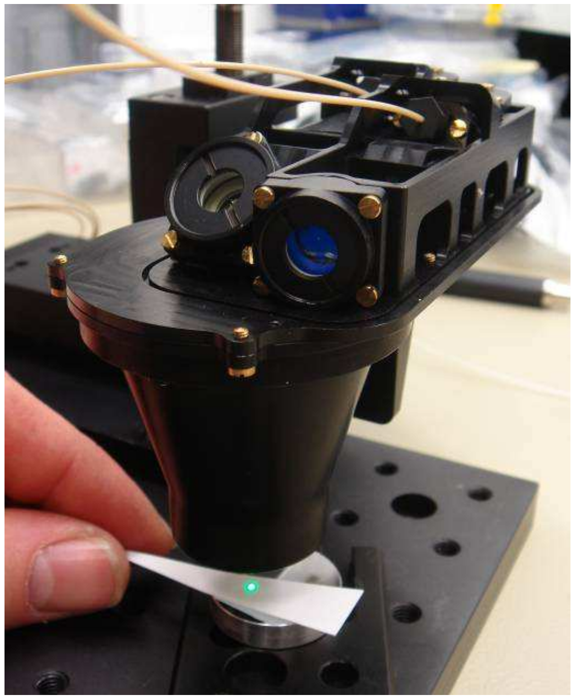

Fig. 6, Raman optical head breadboard during alignment (cover removed)

IV AUTOFOCUS OPTICAL PATH

For the application in the Raman instrument, the laser radiation needs to be focused precisely on the sample surface to achieve a small spot and high irradiation in order to be able to collect a strong Raman signature. A focusing concept was selected which uses the excitation beam itself to find the best focus position. In this confocal setup, the excitation optics is used to receive the backscattered light from the sample surface and to couple it back into the excitation fiber, see Fig. 7.

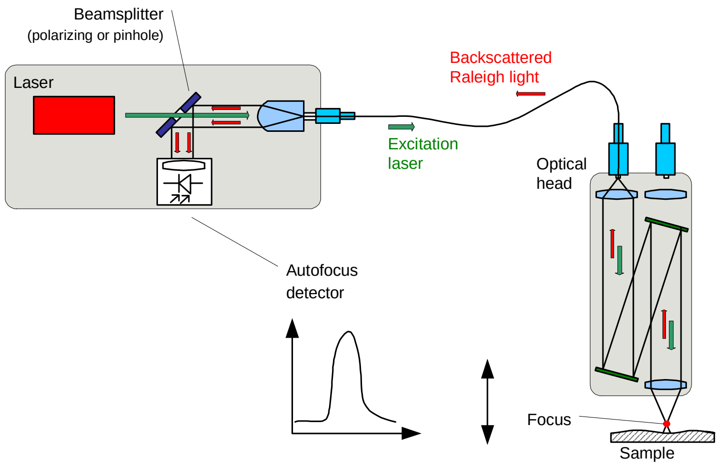

Fig. 7, Autofocus working principle

This coupling efficiency is very poor as long as the laser delivering optical head is not in focus. While the head optics are moved toward the sample surface by a focus actuator, the collection efficiency of the scattered light increases continuously and will reach a maximum when the optical head is precisely in focus. In this position a maximum of backscattered photons are collected by the excitation fiber as the excitation path is exactly reversed. These photons are sent back through the excitation fiber to the laser source. Here this backreflection signal needs to be monitored by a sensitive detector and thus needs to be coupled out of the optical path of the laser. The autofocus detector diode sits next to the laser package and monitors the backscattered photons (Fig.1)
Various methods for splitting off the backreflection signal were investigated and tested experimentally: a power beamsplitter, a polarization beamsplitter and a pinhole mirror. Maximum throughput in excitation and simultaneous high efficiency in coupling out the backreflected light is achieved by the pinhole mirror concept. This autofocus concept, which works by detecting a very low signal intensity (3-5 orders of magnitude lower than the excitation signal strength), drives a number of requirements for the laser design and the passive optical path. The straylight inside the laser needs to be minimized and directed in a way that does not reach the autofocus detector. This results in using a beam trap inside the laser opposite of the autofocus detector. The complete optical path starting with the free beam to fiber coupling interface inside the laser should feature low return loss optical surfaces. This is achieved by "splicing" the fiber directly to the coupling lens as described above (thus avoiding any refractive index gap through air or glue). All fiber endfaces in the optical harness (one fiber to fiber coupling and one fiber to air connection) feature **A**ngled polished **P**hysical **C**ontact connector ferrules (APC) to minimize the backreflection. Additional AR coating on the fiber ferrule endfaces was avoided due to risk of damage caused by the large thermal range. The return loss reduction by angled polished endfaces was found to be sufficiently effective (-36dB freebeam, -40dB connected) for the system.
The autofocus concept with the optical harness, angled polished connectors and the optical head was demonstrated successfully on bulk and powdered mineral samples and extensively investigated for a number of soil and mineral samples.

V. CONCLUSION

The excitation path of the Raman instrument is demonstrated, consisting of a new very compact laser module, a multimode step index launch fiber with new small form factor and lightweight fiber optic connectors and a compact optical head to deliver the laser radiation to the sample.
Low back reflection and minimized stray light allows operation of this optical system in a confocal mode to detect the precise focus position. A technology readiness level of 5 is demonstrated for the individual subsystems which were designed to fulfill the instrument requirement of the Raman instrument on ExoMars.

The compact, lightweight laser, with or without its fiber coupling and the MiniAVIM connector, which is by now commercially available at Diamond, are technologies which are predestined to be used also for other space instruments and missions beyond ExoMars.

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