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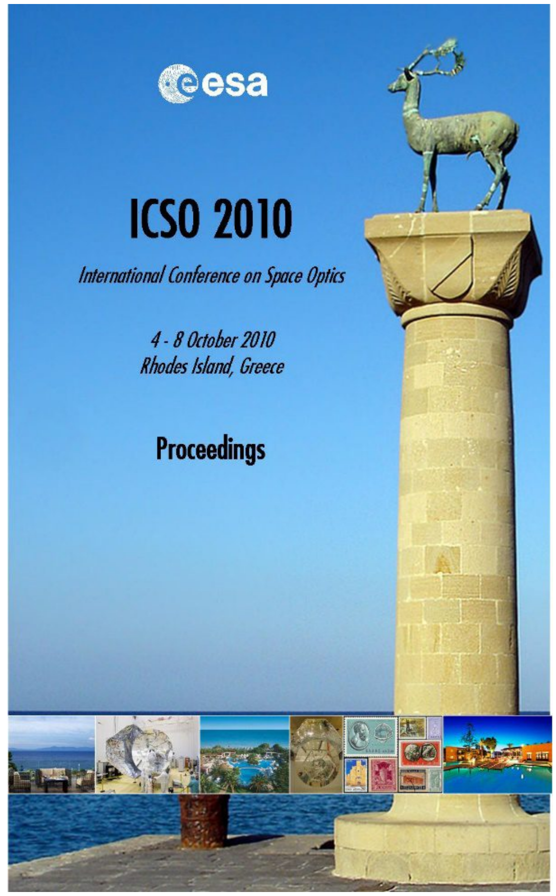

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DEVELOPMENT OF A PULSED UV LASER SYSTEM FOR LASER-DESORPTION MASS SPECTROMETRY ON MARS

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A near-flight prototype of a pulsed UV laser has been developed for the Mars Organic Molecule Analyzer (MOMA) of the ExoMars mission. The laser head is based on a Nd:YAG oscillator with subsequent frequency quadrupling and emits nanosecond pulses with an energy of > 300 µJ at a wavelength of 266 nm. The design is compact and lightweight. Tests in relevant environment regarding temperature, vibration, and radiation have been performed.

I. INTRODUCTION

The joint ESA/NASA ExoMars mission contains a rover to examine the surface of planet Mars with its Pasteur payload. One of the scientific instruments of the payload will be a combined pyrolysis gas chromatograph (GC) and laser-desorption mass spectrometer (LD-MS) called Mars Organic Molecule Analyzer (MOMA) [1-3]. One of the main objectives of the mission and in particular the MOMA instrument is the search for organic molecules as hints of past or present life on Mars. Volatile molecules are evaporated by heating in an oven and analyzed in the gas chromatograph of the instrument, while for the analysis of non-volatile molecules intense laser pulses are used for laser desorption, i.e. bringing them into the gas phase, and weak ionization of the samples for subsequent analysis in the mass spectrometer. A laser emitting nanosecond pulses in the ultraviolet (UV) spectral region is needed as the excitation source. We present a laser system which is developed as a prototype in a near-flight design for use on the ExoMars mission and which meets the optical requirements of the instrument.

II. OPTICAL CONCEPT

The optical requirements of the laser are a wavelength of 266 nm, pulse duration of less than 2.5 ns, and a pulse energy of more than 250 µJ. These pulse parameters have been successfully tested for suitability in the context of LD-MS [1,2]. A beam propagation factor M^2 below 4 was requested. Operation modi will be either single shots, 1 Hz long-term repetition, or short bursts at 10 Hz. Similar UV pulses with much higher repetition rate, but less pulse energy were also used for Raman spectroscopy [4].

The mass budget for the flight model of the laser system including pump diode and electronics is 700 g. In order to obtain a compact design for the laser, the following concept was chosen (see Fig. 1): The laser oscillator is based on a Nd:YAG crystal and emits pulses at the wavelength of 1064 nm. The laser crystal is pumped longitudinally by a fiber-coupled pump diode in order to achieve good mode overlap between the pump light and laser mode. The pump diode has an optical peak power output of 120 W for a duration of 200 µs (qcw), and the optical fiber core diameter is 600 µm. The separation of the pump diode from the laser head by the optical fiber yields two smaller boxes with the possibility of flexible accommodation. Pulsed operation of the laser oscillator is achieved by using a saturable absorber (Cr^{4+}:YAG) as passive Q-switch, which makes the laser concept very compact and simple in terms of further electrical supplies compared to, e.g. active Q-switching. Since a subsequent frequency conversion to the UV region is required, a polarizing element is inserted into the cavity: the extinction ratio of a simple Brewster window turned out to provide stable polarization at the output of the resonator.

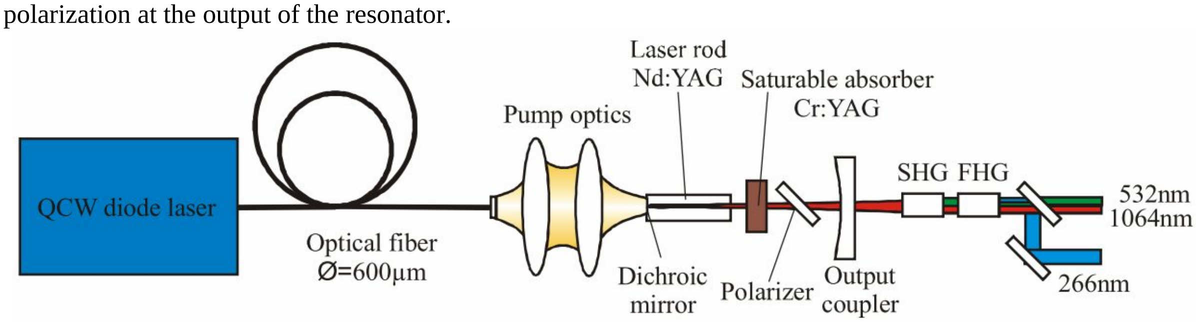

Fig. 1. Optical concept of the laser

The oscillator generates pulses of ~1.5 to 2 ns (depending on the configuration), with pulse energies of more than 2 mJ at the wavelength of 1064 nm. Behind the output coupler, two nonlinear crystals, i.e. KTP and BBO were chosen to generate the second harmonic (SHG) and the fourth harmonic (FHG) at 532 nm and 266 nm, respectively. The overall frequency conversion efficiency is about 20%, which is a quite large value for this compact system without specific beam shaping optics in front of the frequency conversion crystals. Behind the BBO crystal, the UV light (266 nm) is separated by dichroic mirrors from the remaining IR (1064 nm) and green (532 nm) light. The optical concept was successfully tested in a miniaturized laboratory model and yielded the required optical parameters and tolerances.

III. LASER HEAD PROTOTYPE MODEL DESIGN

A flight-like prototype of the laser head has been developed to demonstrate feasibility of such a laser system for harsh environments within the mass budget. The mechanical design is depicted in Fig. 2. All optical components of the laser head are clamped to avoid contamination of the optics by glue. The two nonlinear crystals are clamped in mounts with three rotational degrees of freedom in order to align them within the required mrad tolerances. Behind the laser crystals ("energy monitoring stage" in Fig. 2), the separation of the UV from IR and green light is accomplished, and photodiodes for monitoring of the UV and the green pulse energies are located. The laser head housing is sealed and pressurized with artificial air, which reduces contamination on optical surfaces and increases laser-induced damage thresholds compared to vacuum.

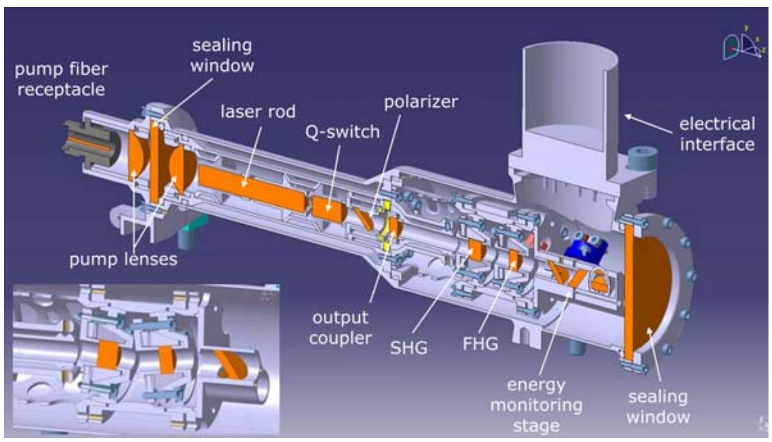

Fig. 2. Mechanical design of the MOMA laser head

The temperature requirements for the laser prototype were (at time of development) -30 to +25°C and -40 to +50°C for operating and non-operating temperature ranges, respectively. Since the nonlinear frequency conversion crystals have to be operated at a distinct temperature in order to maximize the conversion efficiency, the interior of the laser head is temperature controlled at the location of the nonlinear crystal mounts. The internal operating temperature of the crystals is chosen to be above the maximum external operating temperature of the laser head (25°C). Thus, an only-heating approach is feasible using a simple heater foil as active thermal element. A further heating foil is placed on the outer hull of the laser head acting as start-up heater in the cold case. The electrical connector on the laser head feeds the signals for heater, thermal sensors, and photo diodes through the sealed housing.

The prototype model of the laser head (Fig. 3 left) has a length of ~13 cm (without fiber connector) and a mass of 113 g without fiber and electrical harness. On the right photograph of Fig. 3 also the corresponding electronics units as developed by the von Hoerner & Sulger GmbH (vH&S) are shown, i.e., the pump unit which is also a near-flight prototype model and which contains the pump diode, the diode driver, the thermal controllers, and further electronics circuits. The GSE interface is necessary for operation of the system on ground. The total mass of the laser head and pump unit is 850 g, which is more than the 700 g required for the flight model. However, replacing the currently used commercially-off-the-shelf rugged pump diode by a custom diode for the next models (EQM) will meet the mass budget.

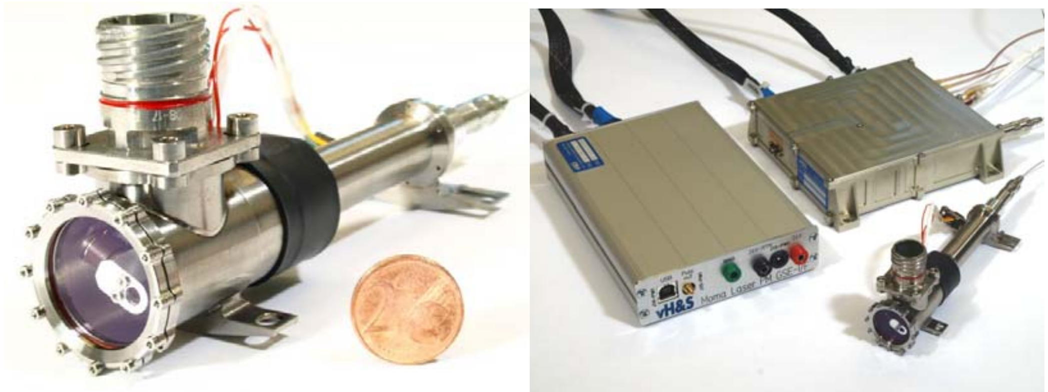

Fig. 3. Right: MOMA laser head. Left: MOMA laser system consisting of laser head (front right), pump unit (back right, by vH&S), GSE interface (left, by vH&S)

IV. OPTICAL CHARACTERIZATION OF THE LASER

Different configurations of the laser head are possible in terms of lengths of the saturable absorber and the nonlinear crystals and their respective optical pulse output parameters. Tab. 1 lists some optical pulse parameters as generated by the oscillator and the frequency conversion stage (fourth harmonic generation, FHG). Typical output beam profiles are shown in Fig. 4 for two different configurations of the laser head, i.e., with shorter and longer nonlinear conversion crystals, which determine the ellipticity of the beam.

Tab. 1. Pulse parameters of the laser head before (IR) and after (UV) frequency conversion

	IR (1064 nm)	**UV (266 nm)**
Pulse energy	1.9 - 2.2 mJ	300 - 450 µJ
Pulse duration	1.5 – 2 ns	1.1 – 1.8 ns
Beam propagation factor M^2	1.5	2 – 4
Pump power	103 - 116 W	
Pump duration	180 µs	
Opt-opt efficiency	10 %	20 % (FHG)

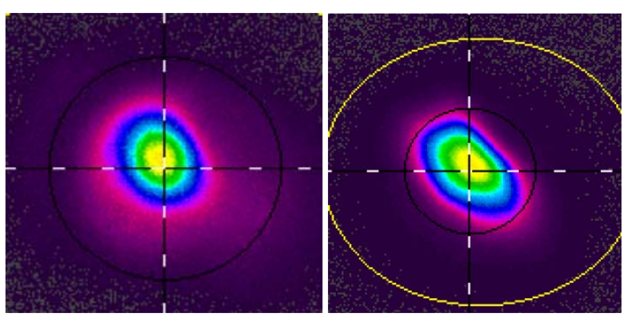

Fig. 4. Beam profiles of the MOMA laser head. Left: configuration with short nonlinear crystals, rather circular beam profile. Right: configuration with long nonlinear crystals, rather elliptical beam profile due to walk-off in the crystals.

As the frequency conversion efficiency of the nonlinear crystals depends on the alignment of the crystals in combination with the temperature applied, the UV output energy decreases, when the internal operating temperature deviates from the design and integration temperature. A typical temperature response is shown in Fig. 5. A temperature interval of approximately +/- 3 K around the optimum temperature keeps the output energy within a range of approx. +/- 10%. Out of the two nonlinear crystals KTP and BBO, this temperature interval is mainly determined by the crystal with the lower temperature acceptance range, i.e., the BBO. This effect can be used to set the UV output energy to lower values, e.g. for energy variation during LD-MS measurement.

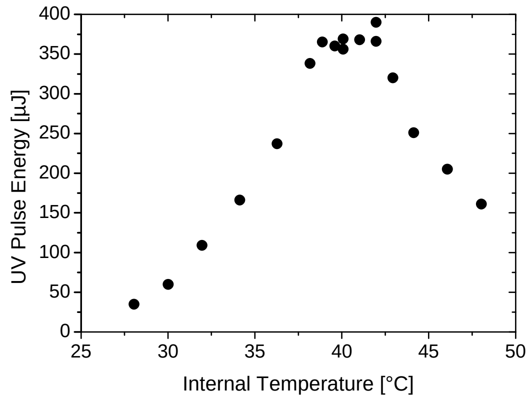

Fig. 5. UV pulse energy in dependence on the internal operating temperature (which is the temperature of the frequency conversion crystals).

V. ENVIRONMENTAL TESTING

The requirement for radiation hardness is 20 krad. As far as possible, fused silica, which is known to be radiation hard [5], is used for optical components except for lenses and the crystals. The aspheric lenses in the prototype model are made of Co550 and will be replaced by radiation hard material SF6G05 in the EQM. The laser crystals (co-doped with Cr^{3+}) and saturable absorber crystals already have space heritage [6]. The radiation effect on KTP at the wavelengths used is known from literature [7], and both the KTP and the BBO crystals have been tested by us to exhibit negligible degradation by irradiation with a dose of 60 krad of 10 MeV protons.

The laser system has been undergone a vibration test with several increasing levels of acceleration, with sine levels up to 20 g and random up to 13 g RMS. Between the single steps of the vibration test, functionality of the laser head was tested regularly, and only a slight decrease in the UV pulse energy was detected, in the end being still well above the required energy of 250 µJ. The first mechanical eigenfrequency of the prototype mounting concept of the laser head was detected to be about 350 Hz in conformance with simulation results.

Non-operational thermal cycling in vacuum and Martian atmosphere (10 mbar of carbon dioxide) has been successfully performed with cycles between -40°C and +50°C. Optical characterization before and after the test revealed no change in the performance of the laser system. The thermal tests have also been used to validate thermal mathematical models of the laser head.

VI. SUMMARY

We have developed a pulsed UV laser system as a near-flight prototype model for the LD-MS instrument MOMA of the ExoMars mission. The laser head meets all the major optical requirements, and it is by design and material selection suitable for the intended mission. Several environmental tests have shown also the compatibility with radiation, vibration and thermal requirements.

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