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International Conference on Space Optics — ICSO 2018, edited by Zoran Sodnik,
Nikos Karafolas, Bruno Cugny, Proc. of SPIE Vol. 11180, 111801B · © 2018 ESA
and CNES · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2535966

UV-DPSS Laser Flight Model for the MOMA Instrument of the ExoMars 2020 Mission

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ABSTRACT

The flight model of the laser system for the Mars Organic Molecule Analyzer (MOMA) instrument within the ExoMars 2020 mission for Martian planetary surface exploration has been developed, assembled, tested, and finally integrated to the NASA Goddard Space Flight Center (GSFC) mass spectrometer. The nanosecond laser system consists of a longitudinally pumped, passively Q-switched Nd:YAG based laser oscillator with a two-stage frequency doubling to 266 nm. The laser design was implemented in robust and lightweight models of the laser head (LH) with the pump unit in a separate electronics box.

In parallel to the laser head integration and testing, materials and optics qualification and acceptance tests have been performed, e.g. to determine the optical damage threshold or the susceptibility to laser induced contamination processes.

Before delivery to the NASA GSFC for integration to the mass spectrometer (MS) flight model (FM), the laser system has been qualified in an environmental test campaign including vibration, shock and thermal-vacuum testing. After delivery to GSFC and integration to the FM MS, the system has been successfully re-tested on the instrument level.

Keywords: Passively Q-switched laser, diode-pumped laser, space-qualified laser, ultraviolet laser, 266 nm laser, ExoMars, MOMA.

1. INTRODUCTION

Diode-pumped passively Q-switched solid-state laser systems enable space-related applications such as laser altimetry and planetary surface exploration techniques, e.g. laser-induced breakdown spectroscopy (LIBS) and laser desorption mass spectrometry (LDMS). The required lasers must be built to withstand the harsh space environments and the challenging requirements in terms of reliability, mass, and power consumption.

In this paper, we will present an overview of the design, realization, and qualification of the flight model of the diode-pumped passively Q-switched solid-state laser for the MOMA instrument, which is part of the ESA ExoMars Pasteur Payload for Martian planetary surface exploration to be launched in 2020 [1]. MOMA will be accommodated inside a rover vehicle. It consists of a pyrolysis/gas chromatography and a laser desorption/ionization mass spectrometry subsystem. The aim of the MOMA instrument is the search for indications of past or present life on Mars, i.e. for signatures of organic molecules and their geochemical context.

As an excitation source for the desorption/ionization of soil samples, a laser with a pulse energy of >125 µJ at a pulse duration of <2.5 ns and a wavelength of 266 nm is required.

2. LASER CONCEPT

2.1 Overview

The MOMA laser system is split into two separate units. The laser pump source and the related driving and diagnostic electronics (laser pump unit, LPU) are separated from the laser head (LH). The conceptual design is shown in Figure.1.

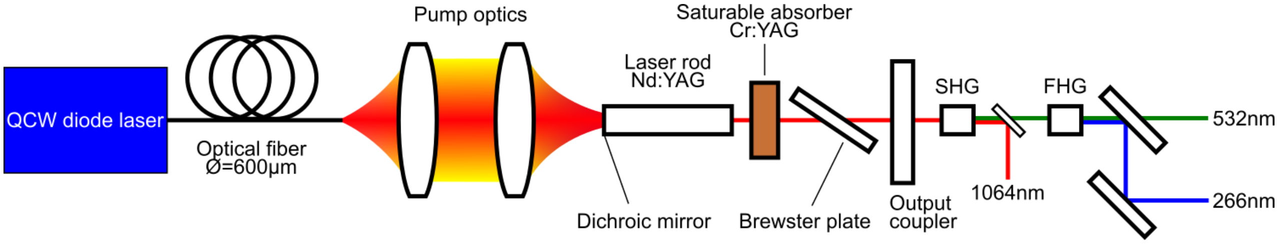

Figure 1. Conceptual design of the MOMA laser.

The LPU is provided by the Max Planck Institute for Solar System Research (MPS – Göttingen, Germany). It contains the fiber-coupled pump diode and all needed electronics to operate the laser system and to interface with the MOMA instrument. The optical fiber allows for a spatial separation of the pump source and laser head within the MOMA instrument. Additionally, it provides good homogenization of the pump light needed for an optimized overlap of pump beam and laser mode inside the laser crystal in order to generate laser pulses with a good beam quality.

The laser concept is based on passive Q-switching of the IR laser oscillator. By this simple concept, nanosecond pulses can be generated without the need for additional high-voltage or RF electronics. Within the IR laser resonator, a Brewster plate is placed in order to enable a stable, linear output polarization as needed for the subsequent frequency conversion. This 1064 nm IR laser pulses are then converted to 266 nm in a two-stage frequency doubling scheme.

2.2 Model philosophy

The MOMA laser head development towards the flight model has taken several years (see Figure 2 for an outline of the development timeline). Starting from first studies and laboratory test models back in 2006, initially a Breadboard Model was developed. This model fulfilled all optical specifications for the laser system and was delivered to GSFC. Here, this model was used for several years to perform LDMS measurements with different development versions of the GSFC-developed mass spectrometer (MS).

After the Breadboard Model, a Prototype Model (PM) was developed to demonstrate the feasibility in terms of mass and volume. This PM was environmentally tested for durability against vibrations and for performance in a thermal-vacuum chamber. This model had a leak-tight outer laser hull to keep the laser active components at ambient pressure. However, this model did not yet have a completely welded housing. In parallel, so-called Miniaturized Laboratory Models (MLM) were set up for detailed experiments on the laser performance in the lab. These models realized mechanical and optical parameters just as they were foreseen for the flight model. However, the mechanical realization allowed a simple variation of all these parameters and, thus, to research on the tolerances of the laser design on mechanical and optical variances.

In 2014, two strongly reduced laser models have been assembled. The Structural Test Model (STM) did not contain any optical or electrical elements but did only represent the mass and mass distribution of the final FM. In particular, it also provided a very similar mechanical response to vibrational or shock excitation. The Thermal and Structural Qualification Simulator Model (QSM) did not provide full laser functionality, either. However, it contained full pump optics, some internal laser optics, thermal hardware and photodiodes. By this, it could be used not only for structural qualification but also for electrical and thermal performance testing and verification.

The Advanced Prototype Model (APM), which was later upgraded to the Engineering Test Unit (ETU), was a fully functional laser model that was also delivered to GSFC and used there for representative tests on their LDMS prototypes. The ETU was the first fully functional laser model with a hermetically tight, laser-welded housing. Following this model, the FM LH was realized and qualified in a protoflight approach.

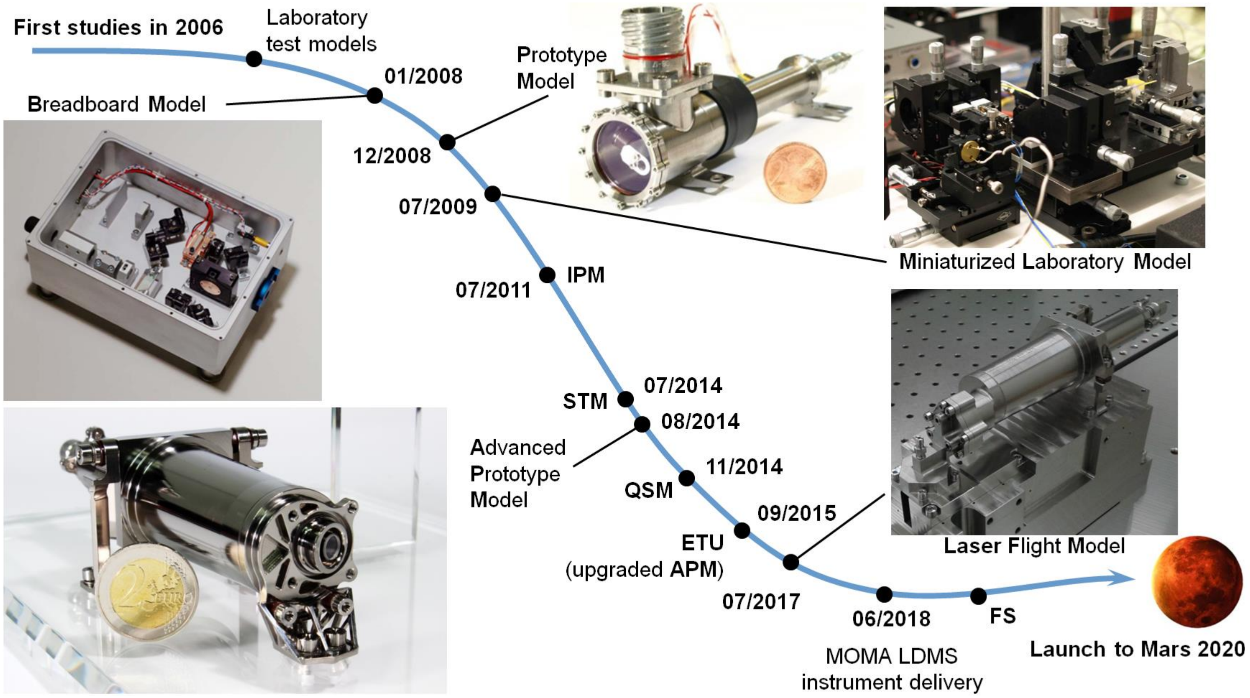

Figure 2. Model history of the MOMA laser.

2.3 Optical design

The detailed optical design of the laser head is shown in Figure 3. It can be divided into 4 different functional subassemblies: the oscillator, the frequency conversion stage, the monitoring stage, and the beam deflection unit.

As mentioned above, the laser oscillator is based on Nd:YAG as laser active medium. This laser crystal is Cr^{3+} co-doped for radiation hardness [2]. Polarization stability is achieved by adding a Brewster plate inside the resonator. Potential pulse-to-pulse instabilities due to coupled resonators are prevented by using wedged optical components. Following the IR oscillator, the 1064 nm pulses are first converted to 532 nm by SHG in a KTP crystal. The unconverted 1064 nm radiation is then filtered out and dumped by a so-called beam-cleaner assembly. Conversion to 266 nm is achieved by SHG in a BBO crystal.

Both the frequency conversion stage as well as the oscillator subassembly are independently temperature stabilized. Temperature tuning of the frequency conversion crystals allows for output pulse energy tuning from maximum pulse energy down to ~10%.

In the following monitoring stage, the 532 nm and 266 nm pulses are separated by dichroic mirrors. Small fractions at both wavelengths are sampled and monitored with respective photodiodes. The main part of the 532 nm radiation is then dumped while the 266 nm pulses pass a telescope to generate the appropriate beam size on the LH-external target.

Finally, a beam deflection unit consisting of a 44°-deflecting Brewster-cut prism allows for precise alignment of the output beam position on the target.

A detailed description of the optical FM LH design can be found in [3].

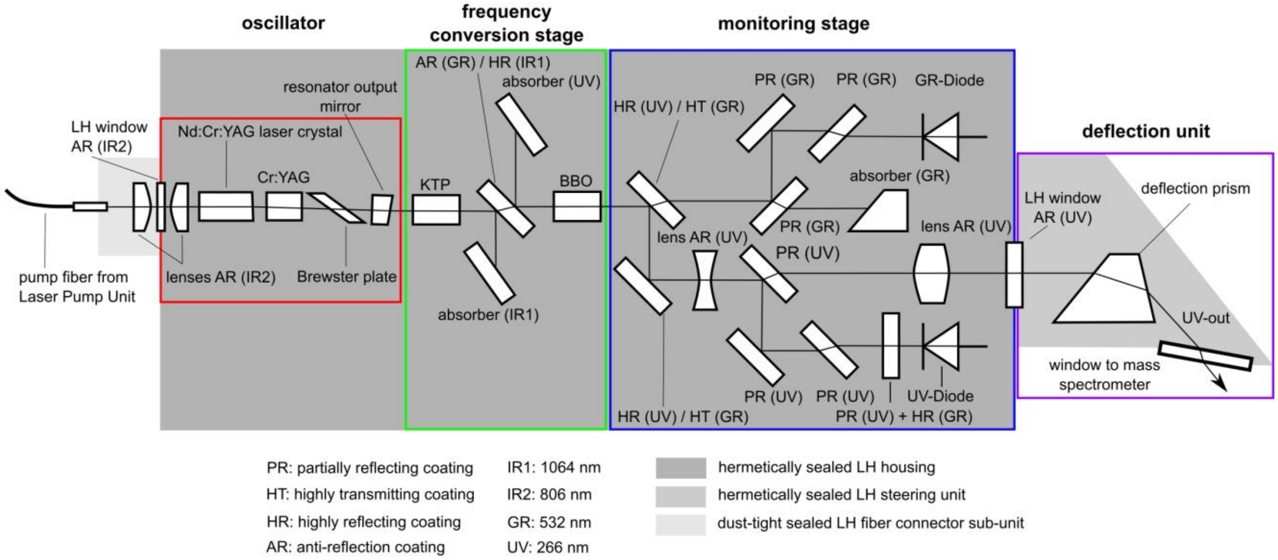

Figure 3. Optical concept of the MOMA LH consisting of four sub-assemblies: oscillator (including pump optics), frequency conversion stage (including beam cleaner), monitoring stage (including beam shaping telescope) and deflection unit.

3. QUALIFICATION AND CHARACTERIZATION

3.1 Optics qualification and testing

The optics for the laser flight model had to pass several qualification and acceptance testing. In particular, all coating designs were subject to initial laser-induced damage threshold testing (LIDT). In addition to S-on-1 tests according to ISO 21254-2, lifetime tests of optics were performed with the laboratory model and the APM. Finally, each selected optic had to pass a raster scan at operational fluence including some safety margin before integration into the flight model.

The effect of laser induced contamination due to the presence of some unavoidable organic compounds inside the enclosed laser hull was evaluated and tested as well. In the laser design process, low-outgassing materials were selected and their use minimized. Although the hermetically tight laser housing allows for a strong reduction of LIC due to the presence of O_2 [4], all organic materials were tested to their susceptibility to cause LIC and found to be compatible with the LH requirements.

3.2 Laser head performance

Before integration to the MS instrument at GSFC, a detailed performance measurement of the LH was carried out. The laser delivered a maximum pulse energy of >130 µJ at 266 nm. The pulse length was measured to be 1.5 ns.

The beam profile slightly varied when the temperature of the frequency conversion stage and, thus, the output energy was changed; see Figure 4 for sample pictures.

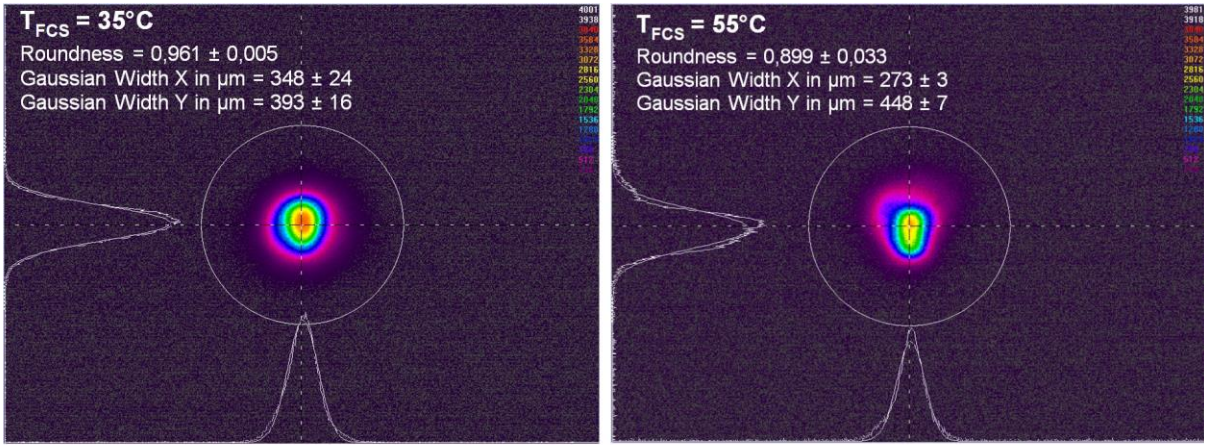

Figure 4. Spatial beam profiles at 266 nm at target distance for two different FCS tuning temperatures (T_{FCS} = 35°C and T_{FCS} = 55°C).

For LDMS measurements, the LH is operated in a burst mode with an intra-burst repetition rate of 100 Hz and a maximum pulse number of 50 per burst. However, the LH is designed for a thermal load corresponding to an average repetition rate of 2 Hz. For this, a temporal delay has to be applied between individual laser pulse bursts.

In Figure 5, a typical energy tuning curve is shown for the LH being operated in burst mode with a fixed number of pre-pulses (pump pulses that are too short to trigger pulse emission from the oscillator but contribute to pre-heating of the laser crystal) and a varying number of main pump pulses (pulses that are long enough to trigger pulse emission from the oscillator).

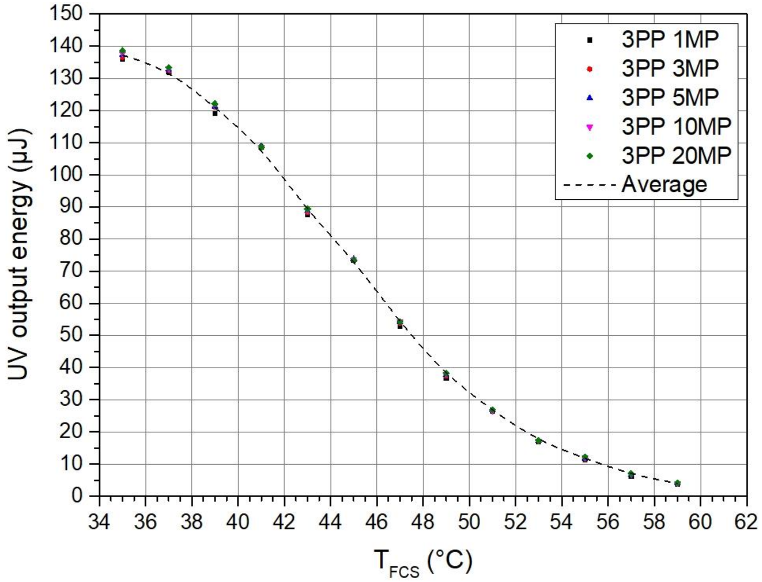

Figure 5. Tuning curve: UV output energy as a function of the frequency conversion stage temperature (T_{FCS}) in burst mode for a varying number of main pulses (MP) per burst.

It can be seen, that the UV pulse energy is almost independent of the number of main pulses and can be thermally tuned from its maximum of >130 µJ to well below 10 µJ.

3.3 Laser head qualification

Before delivery to GSFC for the integration to the FM MS, the FM LH was tested in a protoflight approach concerning vibrational and shock loads and in a thermal-vacuum chamber under Mars atmosphere.

Before and in-between the individual tests and during the thermal-vacuum testing, a characterization of the FM LH performance was carried out. Most relevant performance parameters were maximum pulse energy, the energy tuning behavior, and the position of the laser spot on the target position. Only minor changes of these parameters within the requirements were found and the FM LH passed this measurement campaign. Additional details of the qualification campaign can be found in [5].

After integration to the FM MS at GSFC (see Figure 6), the LDMS instrument was tested thoroughly, again. In particular, the FM LH was subject to vibration testing as part of the LDMS-instrument and was also performance-tested in an LDMS thermal-vacuum test campaign at GSFC.

The FM LDMS instrument did pass these tests and was subsequently delivered to Thales Alenia Space in Turin.

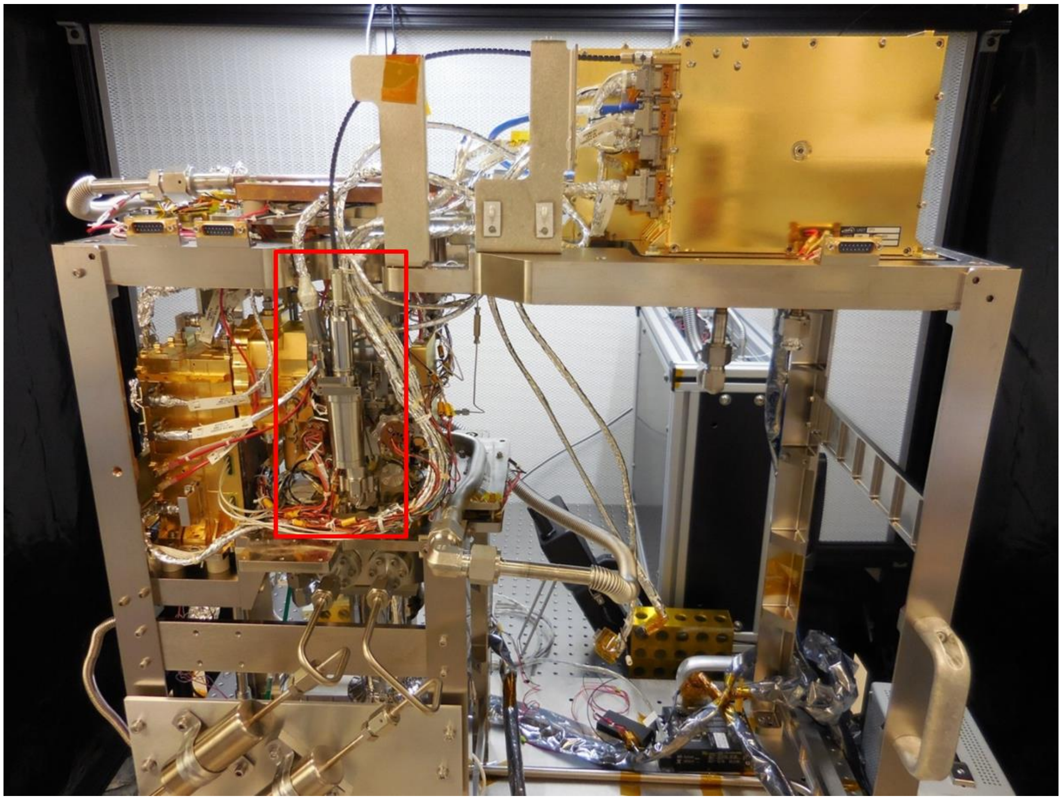

Figure 6. The FM laser head (red box) as it was integrated to the FM MS at GSFC.

4. SUMMARY AND OUTLOOK

The MOMA laser head flight model was developed and qualified in a protoflight approach, delivered to NASA Goddard Space Flight Center, and integrated into the MOMA LDMS instrument. It was successfully qualified on instrument level and finally delivered to Thales Alenia Space Italy as part of the LDMS instrument.

Currently, the LDMS instrument is being integrated into the ExoMars analytical lab drawer (ALD).

5. ACKNOWLEDGEMENT

This work is funded by the Space Agency of the German Aerospace Center (DLR) with federal funds of the Federal Ministry of Economics and Technology in accordance with a parliamentary resolution of the German Parliament (grant no. 50QX1002 and 50QX1402).

Furthermore, the authors would like to thank their project partners MPS and GSFC for a good and fruitful collaboration throughout the course of the MOMA project.

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