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MERLIN laser transmitter for space borne methane sensing

Jana Ammersbach[(a)], Bastian Gronloh [(a)], Tristan Heider [(a)], Hans Huber [(a)], Jörg Luttmann [(a)], Melina Reiter [(a)], Rolf Versteeg [(a)], Hans-Dieter Hoffmann [(a)]

[(a)] Fraunhofer Institute for Laser Technology ILT, Steinbachstrasse 15, 52074 Aachen, Germany,
Lead Author e-mail address: jana.ammersbach@ilt.fraunhofer.de

Abstract: MERLIN (Methane remote sensing LIDAR mission) is a joint DLR/CNES mission, which will measure column densities of methane in the earth's atmosphere. The heart of the instrument is the laser transmitter subsystem, developed and built by Airbus (Ottobrunn, Germany) in cooperation with the Fraunhofer Institute for Laser Technology (Aachen, Germany), being in charge of the laser's optomechanical assembly. The project is currently in Phase D. In this paper we would like to give an overview of the current status of assembly, integration and testing activities.

1. Introduction

The MERLIN mission uses an Integrated Path Differential Absorption Lidar (IPDA) to determine methane concentration with an exceptional precision down to 8 ppb relative error and 1 ppb systematic error [1] . The measurement principle is based on a laser transmitter that emits laser pulses at two wavelengths of around 1645 nm to measure the methane concentration in the Earth's atmosphere [2] . One of the pulses is designed to target a strong absorption peak of methane, while the other pulse is designed to have a low absorbing wavelength for methane, but with nearly identical absorption for other gases as the first pulse. The methane concentration is then determined by calculating the differential atmospheric absorption between these two wavelengths.

The laser system features key technologies, as already demonstrated successfully in the frame of the FULAS project [3] , to enable reliable long-term and high-stability laser performance operation under space conditions. The technologies are optimized with respect to thermal and mechanical stability and developed with special attention to laser induced contamination (LIC) issues by aiming for an inorganic design whenever possible, reducing any critical organic and outgassing materials to single-mg level for the whole laser. The subassemblies used in MERLIN LASO have now been fully qualified, and lifetime testing of critical subcomponents such as the pump diodes has been successfully passed.

This publication provides an insight into the current project status including the passed qualifications and acceptance testing and the performance of the EQM laser model main components.

2. Overview of laser design and mission principle

The laser source that generates the pulses with two dedicated wavelengths consists of three separate sections: The oscillator, the amplifier and the optical parametric oscillator (OPO). The first two sections are needed to generate a strong driver for the optical parametric oscillator for frequency conversion to the needed wavelengths.

The oscillator is a seeded, frequency stabilized, single-longitudinal mode resonator which consists of a piezo-driven cavity length regulation for single-mode operation and a Pockels Cell element for pulse generation. To avoid spatial hole burning, a twisted mode operation in the Nd:YAG crystal is employed.

The amplifier is based on the Innoslab design to achieve pump amplification with stable thermal lensing and low risk of parasitic oscillations.

The OPO is a seeded ring resonator consisting of three fixed dichroic resonator mirrors, a rugged piezo actor which functions as the fourth resonator mirror and is needed for frequency-stabilized operation (Figure 5). Two KTP crystals which are actively temperature controlled are used for the frequency conversion to the needed wavelengths.

More details about the sections can be found in [4] .

3. Overview on critical qualification

The qualification and lifetime testing campaign for MERLIN LASO was finished successfully in 2023.

This includes the optical pump modules (see Figure 1) and piezo actuators, which passed extensive lifetime and environmental testing without significant degradation.

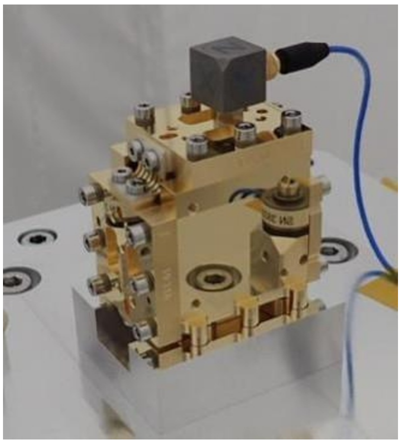

Figure 1: Pump module of the amplifier during vibration testing (including sensors)

The mounting technology OPTOMECH, which is used in MERLIN, proved exceptionally versatile and adaptable. This technology allows for a mirror mount stability of better than 10 µrad tilting within an operational temperature range of 20 K. All optical components that are used, avoid inorganic materials to ensure a maximized lifetime in a pressurized housing. Full qualification was reached for challenging components such as mounts for brittle crystals and large optics. In the frame of MERLIN phase C, mounts for the KTP used in the OPO as well as the Pockels Cell consisting of a BBO crystal were qualified (see Figure 2).

Figure 2: KTP mount (left), Pockels Cell mount (right)

The electrical harness, usually a major contributor for outgassing of organic material, is assembled by using only ceramic and metallic materials for all driving currents, voltages and signals.

4. Performance of the oscillator

The integration of the oscillator for the EQM was completed in May 2023, meeting all performance requirements. A selection of optical output parameters is listed in Table 1. At the working point an optical pump to optical output efficiency of 19% was measured with an output energy of 4.7 mJ at 17 ns pulse duration while maintaining single-longitudinal mode operation and a beam quality of M^2=1.2 in both axes (See Table **1**).

Table 1: Selection of output parameters of the oscillator

Parameter	**Value**
Output Energy	4.7 mJ
Optical pump to optical output efficiency	19%
Beam quality	M^2=1.2
Pulse duration	17 ns
Spectral performance	Single-frequency operation
Pulse energy stability	<0.45% standard deviation over 10 s

An exemplary caustic measurement is shown in Figure 3. The pulse energy stability is excellent with a standard deviation in a measurement interval of 10 s below 0.45%.

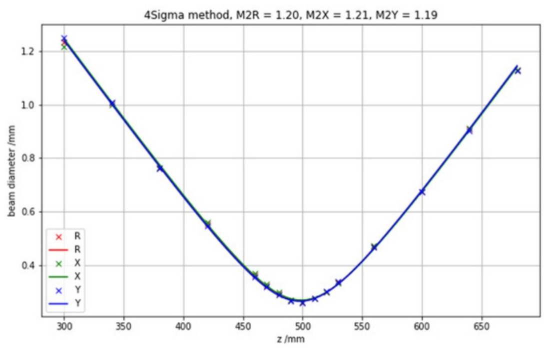

Figure 3: Measurement of beam quality of the oscillator

During the oscillator verification campaign multiple thermal load cases were tested to simulate performance with different oscillator efficiencies to gather data on end-of-life performance and test different thermal budget requirements. The thermal load originating from the oscillator pump diodes and the laser crystal was increased over 40% while exhibiting in-spec performance. This shows that the optical and thermomechanical design exhibits an outstanding thermal robustness due to inherently stable design (facilitated by optical modeling) in combination with ultra-stable mounting technology.

5. Performance of the Amplifier

The integration of the EQM Amplifier was completed in February 2024, meeting all performance requirements. A selection of optical output parameters is listed in Table 2.

Table 2: Selection of output parameters of the amplifier

Parameter	Value
Output pulse energy	35 mJ
Beam quality	M^2<1.3
Pulse duration	17 ns
Overall optical pump to optical output efficiency	20%
Pulse energy stability	<0.4% standard deviation over 10 s

The Amplifier output has a pulse energy of 35 mJ with a beam quality of M^2<1.3 at a pulse duration of 17 ns. An exemplary caustic measurement of the output beam can be seen in Figure 4.

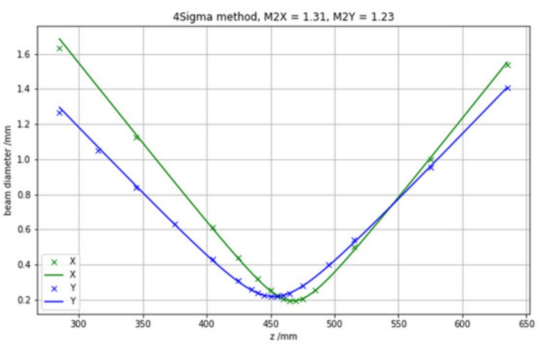

Figure 4: Beam quality of the AMP output

Different thermal load cases were tested to measure the impact of thermal load on the optical performance. With the current setup, the thermal load can be increased by up to 16%. The performance was measured to be stable and within specification for all thermal load levels. The beam profile and pulse energy were unchanged.

6. Performance of the OPO

The OPO is the most alignment critical and

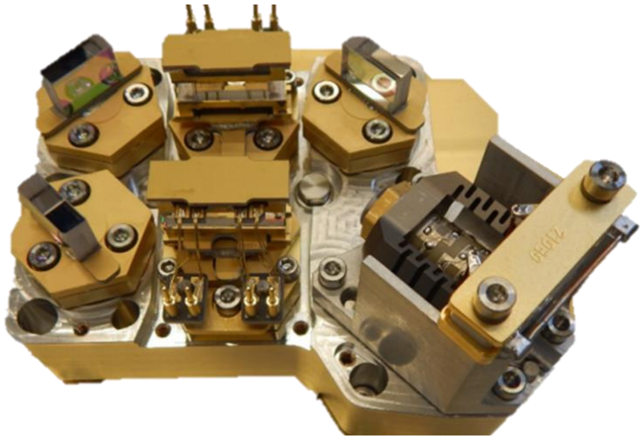

Figure 5: Fully assembled OPO

biggest standalone subunit and was assembled and environmentally tested for both EQM and FM in January 2023 (See Figure 5). In the frame of the pre-assembly all requirements were met.

The OPO is currently being integrated onto the laser bench.

7. Summary and outlook

All necessary qualifications and lifetime tests on subassembly level have been accomplished. Full qualification on transmitter level is expected in 2025. The assembly, integration and test of the oscillator and amplifier for the EQM have been finished successfully with all performance parameters in specification. Thermal load testing has proven that the optical design in combination with the ultra-stable and rugged optical mounting technology exhibits outstanding thermal robustness.

8. Acknowledgements

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[1] C. Stephan et al., "MERLIN: a space-based methane monitor", Proc. SPIE 8159, Lidar Remote Sensing for Environmental Monitoring XII, 815908

[2] C. Wührer et al. , “MERLIN: overview of the design status of the lidar Instrument,” in International Conference on Space Optics — ICSO 2018, Chania, Greece

[3] S. Hahn et al., “FULAS: high energy laser source for future LIDAR applications,” in International Conference on Space Optics — ICSO 2018

[4] M. Livrozet et al., "Optical and optomechanical design of the MERLIN laser optical bench," Proc. SPIE 11852, International Conference on Space Optics — ICSO 2020.