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High energy, single frequency, tunable laser source operating in burst mode for space based lidar applications

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HIGH ENERGY, SINGLE FREQUENCY, TUNABLE LASER SOURCE OPERATING IN BURST MODE FOR SPACE BASED LIDAR APPLICATIONS

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ABSTRACT

This paper describes the laser transmitter assembly used in the ALADIN instrument currently in C/D development phase for the ESA ADM-AEOLUS mission (EADS Astrium as prime contractor for the satellite and the instrument).
The Laser Transmitter Assembly (TXA), based on a diode pumped tripled Nd:YAG laser, is used to generate tunable laser pulses of 150 mJ at a nominal wavelength of 355 nm. This laser is operated in burst mode, with a pulse repetition cycle of 100 Hz.
The TXA is composed of the following units: a diode-pumped CW Nd:YAG Laser named Reference Laser Head (RLH), used to inject a diode-pumped, Q-switched, amplified and frequency tripled Nd:YAG Laser working in the third harmonic referred as Power Laser Head (PLH) and a Transmitter Laser Electronics (TLE) containing all the control and power electronics needed for PLH and RLH operation.
The TXA is made by an European consortium under the leadership of Galileo Avionica (It), and including CESI (It), Quantel (Fr), TESAT (Ge) and Thales (Fr).

1 INTRODUCTION

The ALADIN TXA, assigned in an open competition between two European teams to the consortium lead by Galileo Avionica, is the result of a technological effort funded by ESA, lasting more than 10 years, and mainly devoted to improve the European technology of All-Solid-State laser sources suitable for spaceborne Lidar long lifetime missions [1, 2, 3].
The ALADIN Instrument and TXA will be respectively the first European spaceborne Wind Lidar, and All-Solid-State laser Transmitter to be launched in 2007 for a three-years mission.

2 ALADIN INSTRUMENT

The ALADIN instrument [4] is a Direct Detection Doppler Wind Lidar, devoted to wind profiles measurements over an altitude range up to 16 km with an accuracy of 2 m/s, with global earth coverage. The instrument architecture is organised around the following main assemblies:
– the Laser transmitter assembly,
– the 1.5 m diameter all-SiC Telescope,
– the Receivers, based on Mie Fizeau spectrometer and a Rayleigh double-edge Fabry-Perot spectrometer, associated to accumulation CCD's.

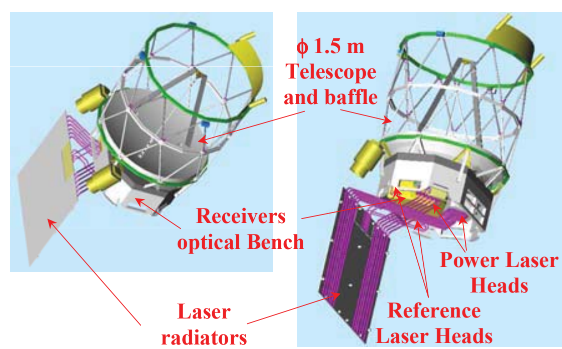

Fig. 1. The ALADIN instrument overview

3 TXA REQUIREMENTS

The Transmitter Assembly is based on a diode-pumped tripled Nd:YAG laser providing a high energy pulse at 355 nm. It is operated in burst mode with 100 Hz PRF, full performances over 7 seconds and a burst repetition period of 28 seconds. There are two fully redundant transmitters, each including a laser head (PLH and RLH [5]) and a transmitter laser electronic (TLE).
The main TXA performance requirements at 355 nm are reported in the following tables.

Table 1. Laser Output Requirements

Parameter	Aladin TXA
Energy/pulse	$\geq$ 150 mJ
Polarisation	Linear, better than 100 :1
M^2	< 3.5
Pulse duration	≤ 100 ns FWHM
Pulse linewidth	≤ 50 MHz FWHM
Spectral purity	99% of the pulse energy within 90MHz
Frequency stability	< 4 MHz rms over the measurement time
Tunability	±7.5GHz for adjustment ±5 GHz in calibration mode
Tuning accuracy	<1 MHz rms over 28 min (noise) <1.7 MHz rms over 28 min (slow drift)

Table 2. Physical & Environmental Requirements

Parameter	Aladin TXA
Mass	PLH + RLH < 31 kg TLE < 23 kg
Stiffness (first eigen-frequency for rigid boundary conditions)	PLH > 140 Hz RLH > 300 Hz TLE > 300 Hz
Cold plate interface temperature (single side conductive cooling)	22°C ± 1°C
Non operating temperature range	-40 °C ÷ +50 °C
Random vibration level	14 g rms
Average power consumption	< 470 W

The most stringent requirements that have conditioned and driven the laser architecture and design choices are:

- Frequency stability and tuning accuracy.
- Environmental requirements, especially mass, stiffness and thermal I/F with Aladin instrument.
- Lifetime.

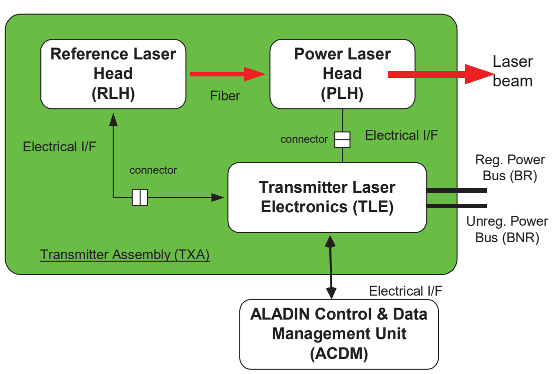

Fig. 2. TXA functional block diagram

4 TXA ARCHITECTURE AND DESIGN

The TXA structure is organised in 3 units:

Reference Laser Head (RLH) [5]. The RLH is an ultrastable diode-pumped CW Nd:YAG Laser, used as injection seeder for the PLH. The output beam of the RLH is fed into PLH by means of an optical fibre.

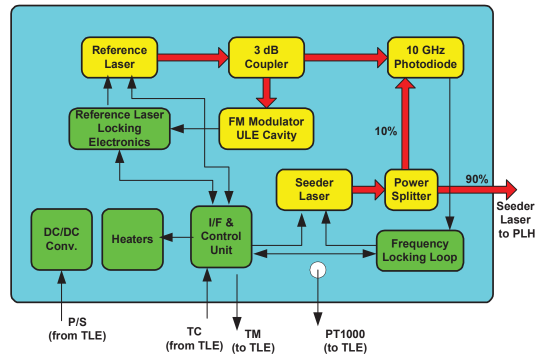

Fig. 3. RLH functional block diagram

Power Laser Head (PLH). The PLH is a diode-pumped, Q-switched Nd:YAG Laser frequency tripled and it is composed of 4 main subunits:

- A low energy Nd:YAG Master Oscillator (MO), injection seeded Q-switched and longitudinally pumped by laser diodes (LD).
- A first amplifier (PreA) in a double pass configuration (transversally diode pumped).
- A second power amplifier (PwA) in a single pass configuration (transversally diode pumped).
- A Harmonic Section (HS) employing two non-linear crystals.

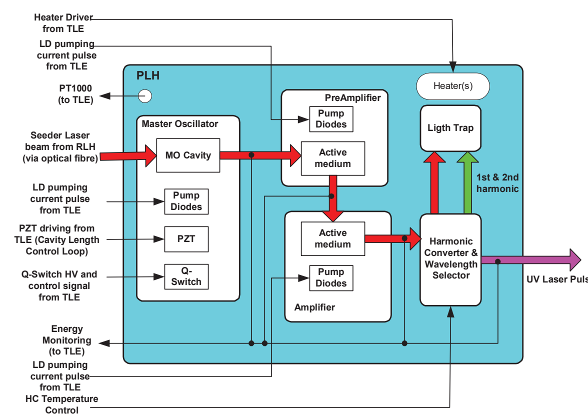

Fig. 4. PLH functional block diagram

Transmitter Laser Electronics (TLE). The TLE is organised in two main sections:

– Power Section, containing the Laser Diode Power Supplies for MO, PreA and PwA and the High/Low voltage Power Supply;

– Interface & Control Section containing several boards dedicated to command and control PLH and RLH operations and interface the Aladin Control and Data Management (ACDM).

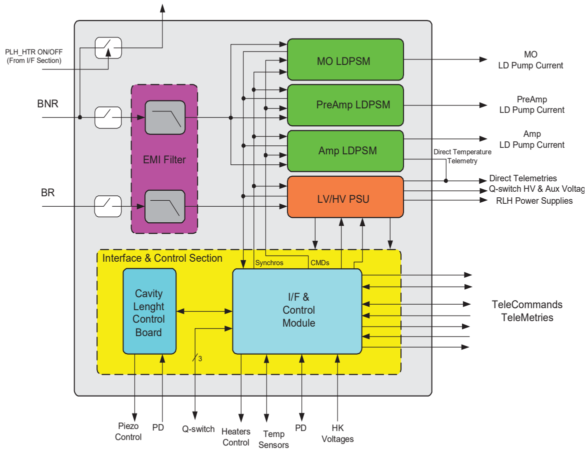

Fig. 5. TLE functional block diagram.

The PLH is the most critical unit to obtain the overall TXA performance. In order to comply with the stringent output requirements, its laser architecture has been structured separating the spectral and tuning performance from the energy and spatial characteristics. The former have been achieved by a low energy MO locked to a frequency tunable single-frequency stabilised seeder (RLH). The latter are obtained by a double amplification stage, designed to extract the requested energy and preserving the initial spectral performance, without significant degradation of the MO good spatial quality.
Finally the radiation frequency is doubled and tripled in the high efficiency Harmonic Converter section, to obtain the required output wavelength.
The PLH optical layout is shown in Fig. 6.

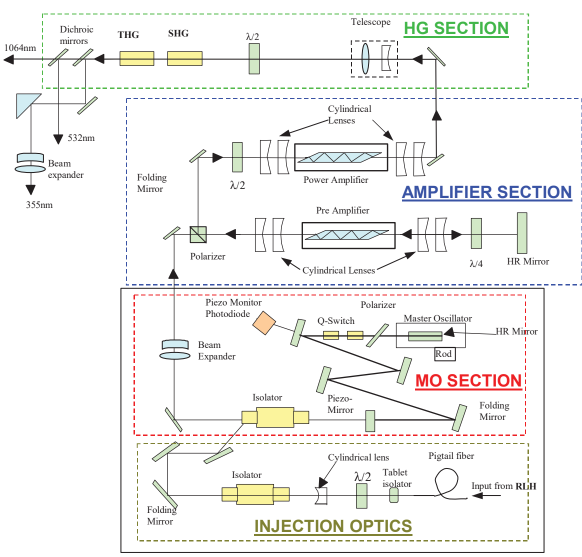

Fig. 6 PLH overall optical lay-out

4.1 *PLH Detailed design*

Master Oscillator

The Nd:YAG Master Oscillator, operating at 100 Hz, continuously pulsed regime, is longitudinally-pumped with a Thales two dimensional laser diode stack, derived from the commercial model TH-Q1312-B Quasi-CW stacked array GaAlAs laser diodes, emitting at 808 nm, 840 W of peak optical power, 1.5% duty cycle, with fast-axis collimation and focusing optics. The scheme of MO is shown in Fig. 7.
The laser material is cylindrically shaped with 5-mm diameter and 15-mm length. The HR spherical mirror is directly manufactured onto the pump face of the laser rod, which is HT at the 808 nm pump LD's wavelength.
The end-pumping geometry has been chosen to obtain the predicted performance in terms of output energy (> 11 mJ), optical beam quality close to diffraction limit and Q-switching laser pulse duration around 30 ns. The laser resonator with optical length of ≈80 cm is 4-times folded. The laser cavity optics include the HR rear- and folding-mirrors, the output coupler (60 % R at 1064 nm) and the EO-Q-switch, including polariser and Pockel's cell in double-crystal, thermally-compensated configuration.
The MO is injection seeded through the output coupling mirror using a Faraday isolator, providing also the required optical isolation from the amplifying stage. An active control of the resonator length is required to ensure stability of the emitted laser beam frequency and against unpredictable multi-longitudinal mode operation. The amount of pulse-to-pulse frequency jitter is related to the accuracy of the length control. To this purpose MO frequency locking to RLH has been achieved through a dedicated non continuous hardware/firmware (HW/FW) Cavity Length Control Loop (CLCL). Acting just before each laser pulse the cavity length is scanned with a piezoactuator over its entire Free Spectral Range in order to find the optimal condition for the single mode operation.
The selected Q-switch electro-optics device needs no active temperature stabilisation control because of intrinsic thermally compensated scheme [6].

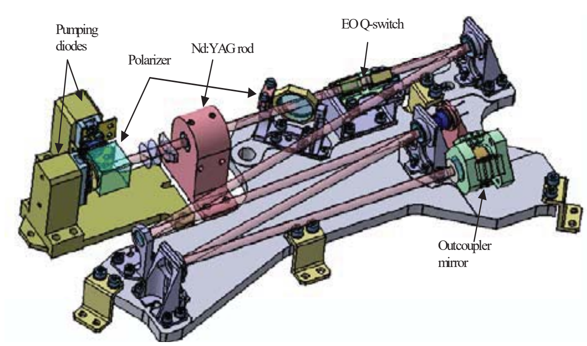

Fig. 7. MO optical lay-out and mechanical redundant packaging.

Amplifier Section

The double amplification stage is intended to produce up to 500 mJ pulses at 100Hz with ≤ 20ns FWHM pulse duration. The target beam spatial quality factor is $M^2<3.3$ and the beam polarization ratio ≥ 96%.

Low M², high extraction efficiency, conductive cooling and reduced parasitic oscillation have led to the choice of a slab shaped Nd:YAG active material in a zig-zag path configuration with Brewster cut at input-output [7].

Due to the low radiation level in the operating environment and the reduced effect on the pump and laser wavelength absorptions no Cr doping of the active material has been selected.

Each amplifier active material is pumped by 8 Thales LD diodes with 2 % duty factor. The diodes are directly coupled to the active medium in order to increase the coupling efficiency and to be less sensitive to vibrations in so far as a minimum of optical components are involved in the light coupling. The optical coupling efficiency has been assessed to be >99%.

The amplifiers optical layout and mechanical packaging is reported in Fig. 8.

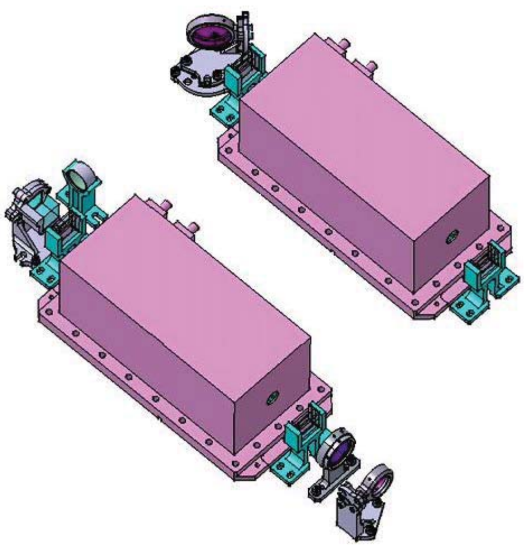

Fig. 8. Amplifiers optical layout and mechanical packaging

Numerical ray tracing model in conjunction with Frantz-Nodvik [8], [9] amplification model have been used to determine the gain distribution and the energy amplification in order to favour a low M^2 at the output of the amplifiers. The simulations have shown that this setup represents the best configuration to reach the goal of several hundreds of mJ@1064 nm at the output of the second amplifying head.

The cooling architecture, entirely conductive, is based on pumping from two opposite sides in the Total Internal Reflection (TIR) plane and cooling in the perpendicular plane.

This configuration shown in Fig. 9 has been optimised by using a thermal model in order to reduce the warm-up time (time to reach the thermal stabilization) at the beginning of each burst. This enables to get stable beam characteristics during the 7 useful seconds of laser operation in terms of required pointing stability and divergence.

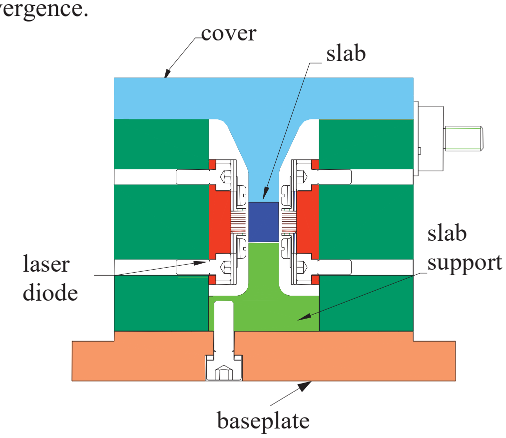

Fig. 9. Pumping-cooling configuration

Harmonic Section (HS)

Concerning second harmonic (SHG) and third harmonic (THG) stage, the frequency converter has been designed for maximum angular acceptance bandwidth, which excludes the use of BBO in favour of LBO crystals.

The adoption of a LBO-LBO scheme leads to the need of relatively long (20 mm) crystals at constant beam cross section and of temperature stabilisation for both the SHG and the THG. Because of the significantly reduced walk-off effect in LBO, the length doesn't negatively influence the converter performances.

For the simple selected arrangement of type I LBO SHG plus type II LBO THG, the temperature acceptance of the THG crystal requires control tolerances to ± 0.1 °C to limit the THG fluctuation. In Fig. 10 the harmonic crystals mechanical mounting including active thermal control is shown.

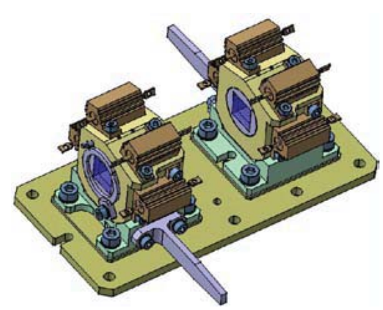

Fig. 10. Harmonic crystals mechanical packaging.

4.2 *THERMO-MECHANICAL ARCHITECTURE*

The main requirements that have driven the PLH thermo-mechanical architecture choices are the mass, the stiffness, the single side thermal I/F with Aladin instrument and the mechanical load induced at this I/F by the satellite heat-pipes and the residual interface forces/ torques at the main structure levels. In Fig. 11 the PLH on-ground purged housing configuration is shown.

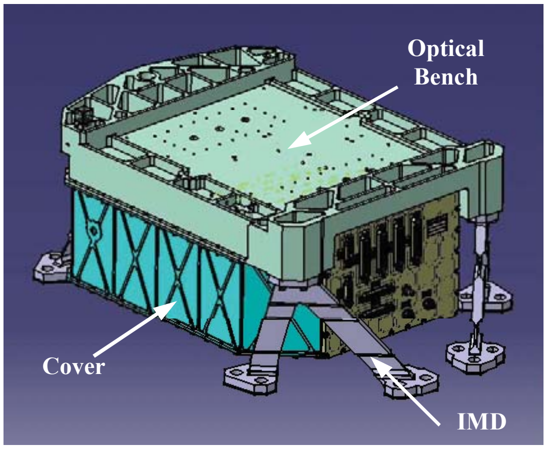

Fig. 11. PLH mechanical design

It is basically constituted by an Isostatic Mounting Device (IMD), a Cover and a double Optical Bench (OB).
The IMD is constituted by three bipods made in Ti Alloy in order to achieve a good thermal insulation of the PLH from the Aladin Main Structure, to guarantee the required stiffness (f1 ≥ 140 Hz) and to withstand the mechanical loads coming from the satellite cooling system without producing sensible laser misalignment. All the electrical and optical connectors are located on a side of the Cover.
As shown in Fig. 12 and Fig. 13 the OB is in turn constituted by two plates supporting all the optical subunits and components: the upper plate and the lower plate.

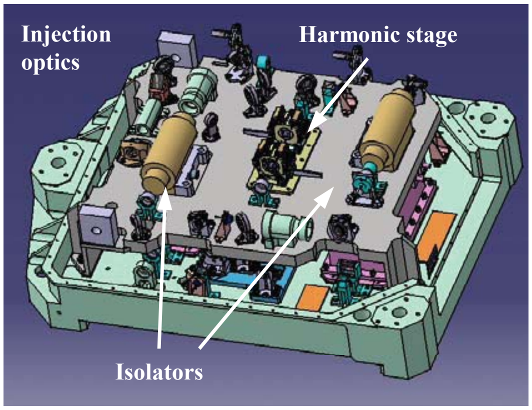

Fig. 12. PLH lower optical bench

The cover and the lower plate are fixed and conductively coupled to the upper plate which acts as main structure of the PLH and cold plate. The final packaging of the optical components has been dictated by the constraint to have all the dissipating elements on a single plate and fulfill the PLH volume requirements. Consequently OB upper plate, whose external surface is mechanically and thermally in contact with the satellite cooling system, houses the most heat dissipating subsystems of the PLH (MO, Pre-Amp and Power-Amp). The Harmonic conversion stage and the MO injection optics, including the optical isolators, are allocated in the lower plate. Optical passages from one plate to the other are foreseen to optically connect the main subunits. Both plates and the cover are built in Aluminium Alloy. A dedicated structural model (FEM) has been utilized to define the IMD and the OB mechanical configuration.

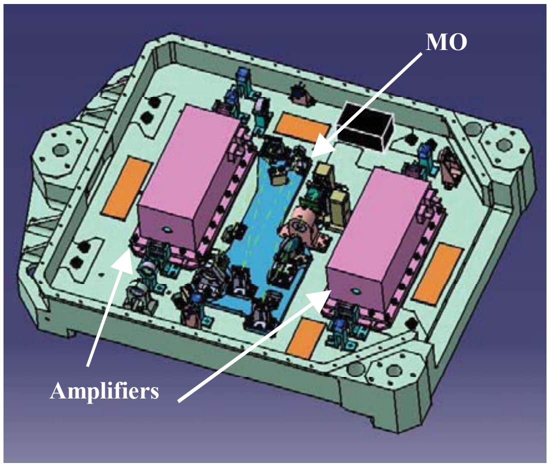

Fig. 13. PLH upper optical bench

To guarantee a reasonable observability during in-flight operations, to maintain constant the laser output energy during all mission and to prevent catastrophic failures of the TXA, several energy (photodiodes) and temperature sensors (thermistors) have been allocated inside the PLH and the relevant information will be managed by the TLE that will communicate them to the ACDM.

Energy sensors are put respectively at the output of the MO, of the PreA and of the PwA stages. This provision will allow, through the telemetries, to check that all the laser stages will deliver the expected energy and remotely compensate, for instance, LD ageing.
An energy sensor is even located at the output of the TXA, to monitor the actual energy emission in the UV.
These information, together with those coming from the temperature sensors, located within the MO, PreA and PwA modules, allow verifying that the Laser Diodes and the active materials are within defined limit and that the TXA can be considered as ready to provide full performance and optimal beam quality.

4.3 LASER BREADBOARD

The TXA laser architecture and the main design choices of the PLH subunits have been validated realizing a breadboard. The breadboard, developed under an ESA technology development contract [10], represents a feasibility experiment for the predicted flight transmitter laser output performance.
The laser breadboard (LBB) optical scheme is reported in Fig. 14, in which two separated optical benches have been conceived: one dedicated to Seeder and MO and the other one to Amplifiers and Harmonic Section.

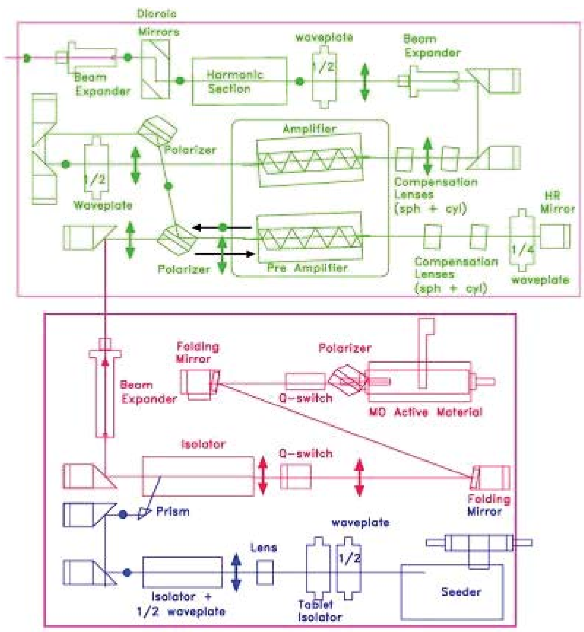

Fig. 14. Optical lay-out of the laser breadboard.

In Fig. 15 a view of the laser breadboard is shown, where the two separated optical benches are visible.

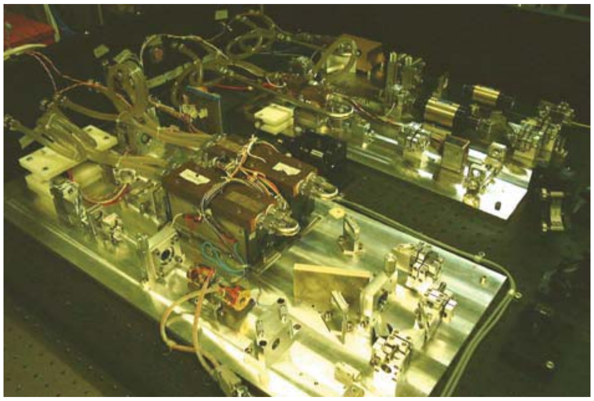
Fig. 15. Laser Breadboard view.

The main results achieved with such a breadboard in the UV spectral region are reported in Table 3. In Fig. 16, the temporal evolution during the burst energy and polarization of the outcoming beam are reported. A typical pulse temporal shape along with its FFT is shown in Fig. 17.
Fig. 18 and Fig. 19 show the UV spatial beam characteristics in the near and far field.

Table 3. UV experimental results measured on the LBB.

Parameter (end of burst)	Values
Energy (mJ)	130*
M^2_x / M^2_y	2.2 / 3.3
FWHM pulse $\Delta\tau$ (ns)	11.3
FWHM B/W (MHz)	17.4
Polarization	Linear, >25dB

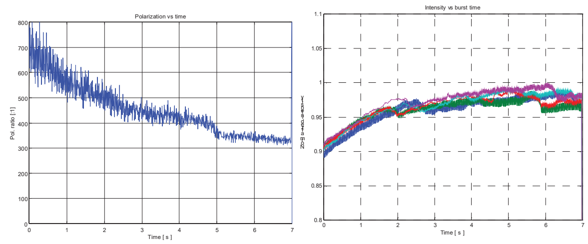

Fig. 16. UV beam polarization ratio and UV energy during 7s burst periods (measured peak value* 130 mJ)

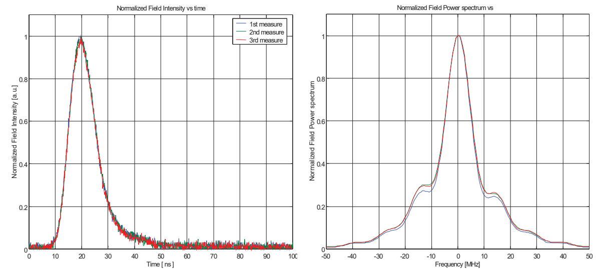

Fig. 17. UV temporal pulse shape and its FFT.

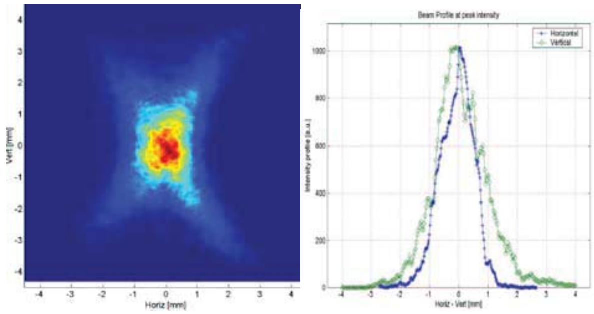

Fig. 18. UV Near field Beam Profile

* PreA energy extraction not optimised

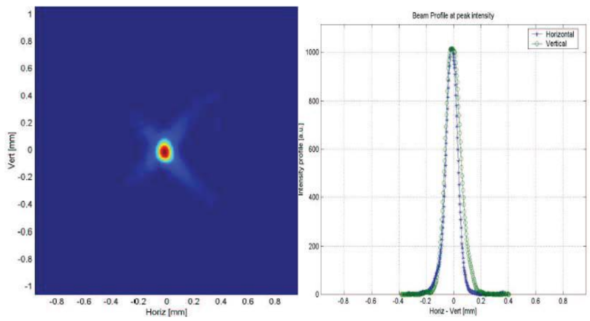

Fig. 19. UV Far field Beam Profile

5 MAIN CRITICAL AREAS

The **space qualification** of laser elements represents a very critical area. In order to increase the optical components reliability, the qualification for laser optics, concerning materials and processes selection, is based on two main issues:
– laser induced damage;
– contamination combined laser effect.

Regarding the first point, the power amplifier and harmonic conversion sections, are exposed to the highest risk of laser damage, because of the highest fluence of optical power in both IR and UV spectral regions. So the design is based on an optical fluence on these critical components two-three times lower than the literature “known” laser damage threshold values. On the other side the selection and qualification of these components will be oriented to obtain higher laser damage threshold values.
Concerning the second point, the PLH non pressure sealed (vented) architecture foresees the laser functioning in vacuum during the in-flight operations and in a dry atmosphere during all the on-ground operations with the aim to avoid contamination of the internal sensible elements (laser diodes, active materials and optics).

At the moment the following special components are considered not yet qualified for a space application:
– Laser Diodes
– Optical Isolators
– Photodiodes
– HR Coatings
– AR Coatings
– Optical Fiber Splice Coupling
– SHG and THG Crystals

The overall reliability factor is largely dependant on the lack of maturity of the Laser Diode Technology.
Suitable screening procedure at bar/stack level by means of dedicated evaluation studies (lead by ESA) and Lot Acceptance Tests for the FM diodes have been programmed to produce LDs with enhanced lifetime (3.4 Giga-shots at constant optical power) and survivability to space environment.

Another challenging aspect is represented by the thermo-mechanical architecture devoted to some components thermal control and overall laser mechanical stability.
The first aspect is driven by the high thermal loads to be dissipated varying in time during burst operations.
The second is related to the difficulty in preserving the laser alignment during the severe vibration levels of the launch due the high optical layout complexity.

6 SUMMARY

In this paper we describe the activities devoted to realize the first European All-Solid-State laser transmitter capable to operate in a three-years mission. It is based on a diode-pumped tripled Nd:YAG laser providing 150 mJ pulse at 355 nm, operated in burst mode with 100 Hz PRF and a repetition period of 28 seconds. The selected architecture has been validated by a dedicated breadboarding activity devoted to verify the main laser output performances.

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