Recent Progress on UV Lasers for Airborne and Space-Based Applications

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Abstract: We have recently been developing two single-frequency UV laser systems for airborne and space-based applications. One is a 200 Hz, 35 mJ laser system for the Optical Autocovariance Wind Lidar being built by Ball Aerospace for airborne wind measurements. The other is an ESTO funded project intended to advance the TRL of space-based UV lasers to 6. It is designed to provide a 355 nm output of 100 mJ/pulse at 150 Hz. This paper discusses the design and recent testing of these two laser systems.

Keywords: UV lasers, single-frequency lasers, space-based lasers, TRL 6 lasers, diode-pumped lasers

1. UV Lifetime Demonstrator

A 15 W, 50-200 Hz UV laser with a lifetime in excess of 1 billion shots is an enabling technology for a number of potential space-based lidar missions that have been identified as priorities in the NRC Earth Science Decadal Survey. Examples of these missions include the following.

1. Aerosol/Cloud/Ecosystems (ACE) – This mission will be an expanded scope follow-on to the highly successful CALIPSO cloud and aerosol lidar mission. Researchers at NASA Langley [1], and at NASA GSFC [2], have been developing three wavelength (1064 nm, 532 nm, and 355 nm) High Spectral Resolution Lidar (HSRL) systems as candidate technologies for the ACE mission.
2. 3-D Winds – Space-based measurements of tropospheric winds with global coverage have been identified as a key mission for both weather and climate modeling. 355 nm airborne demonstrators for this mission include a direct detection wind lidar that was built at GSFC [3], and an Optical Auto-Covariance Wind Lidar (OAWL) being developed at Ball Aerospace [4].
3. Global Atmospheric Composition Mission (GACM) – A scaled up version of the 355 nm pumped Ozone DIAL system being developed at NASA Langley [1, 5] is a strong contender for the GACM mission requirements for global ozone measurements.

The design of a 355 nm UV Lifetime Demonstrator (UVLD) we built to advance the TRL for space-based UV lasers is shown in Figures 1 and 2. It uses a master oscillator/power amplifier (MOPA) approach that incorporates diode-pumped Nd:YAG slabs as the gain media. The key are features derived from previous Phase 2 SBIRs as well as the ICESat-2 laser transmitters [6].

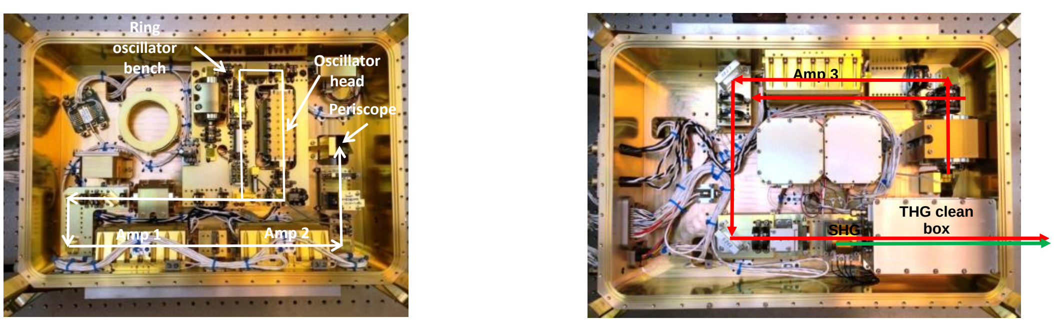

Figure 1. UVLD oscillator/pre-amplifier (l) and power amp/nonlinear converter(r) compartments

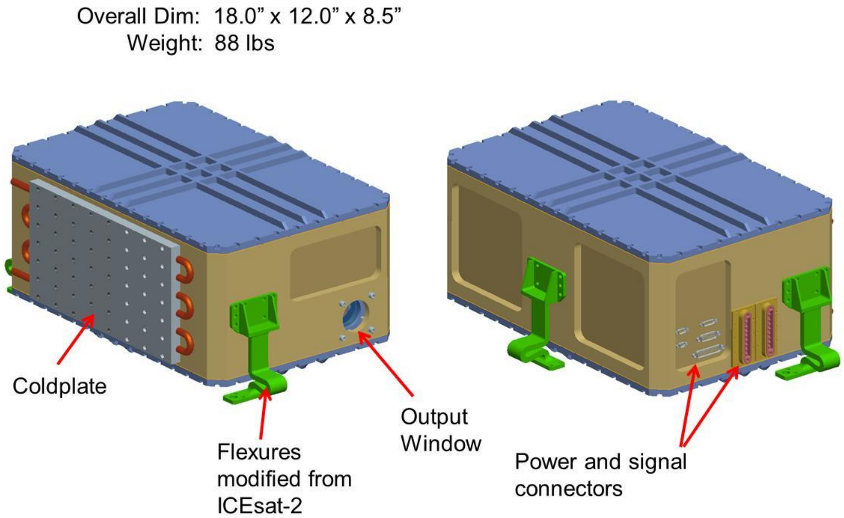

Figure 2. Dimensions, weights and interfaces of the UVLD laser optics module

The overall dimensions, weight, and external interfaces (thermal, optical, mechanical, and electrical) of the laser optics module are illustrated schematically in Figure 2. The cooling is pure conductive to a single interface. The cold plate connected to the single interface shown in Figure 6 could be easily replaced by a heat pipe interface for a flight system. The flexure mounting design was derived from the flight-qualified ICESat-2 design and analyzed to show that it would survive the same vibration testing regimen to which the ICESat-2 lasers were tested.

The UVLD laser has been built and tested through the second harmonic generation stage. The performance at various stages of the optical train is given in Table 1. All of these performance parameters meet or exceed the original performance goals.

Table 1. Performance of the UV Lifetime Demonstrator

Parameter	Goal	Demonstrated
Repetition rate (Hz)	150	150
Oscillator energy (mJ)	≥ 25	34
Oscillator beam quality (M^2)	≤ 1.5	1.3
Oscillator linewidth (MHz)	≤ 100	< 70
Preamplifier energy (mJ)	≥ 150	> 200
Preamplifier beam quality (M^2)	≤ 1.8	1.5
Power amp energy (mJ)	≥ 250	275
Power amp beam quality (M^2)	≤ 2.0	1.9
532 nm energy (mJ)	≥ 135	165
532 nm beam quality (M^2)	≤ 3	2.2
355 nm energy (mJ)	≥100	TBD
355 nm beam quality (M^2)	≤ 4	TBD

The UVLD is now undergoing a series of lifetime tests in preparation for vibration and thermal/vacuum testing that will raise the TRL to 6. The life tests include the following.

1. A 4 month, 532 nm only lifetest of the UVLD laser to assess the 532 nm lifetime. All optics except the LBO tripler were installed in the output optical train of the laser. The purpose of this test was to verify the LBO doubler coating and the cleanliness of the 1064 nm laser transmitter.

a. This test had completed with 1.3 billion shots as of April 2016.
b. Total power was down 9%
c. 532 nm power was down 19 %.
d. There was no damage to any optics
e. The power loss has been determined to be primarily due to a drop in the oscillator power.
f. The oscillator is being reconfigured to run with a lower drive current and longer pulsewidth to reduce the decay rate for the remaining tests

2. A 4 month, half-power 355 nm life test of the laser transmitter for initial UV lifetime assessment will be initiated after the oscillator operating conditions are updated.
3. A 4 month, full power 355 nm life test of the full UVLD laser transmitter for final UV lifetime assessment will be initiated after the half power UV test. This test will not provide validation of our approach for a full 3 year mission but will provide trend data on any UV degradation that may occur.

After the life testing is completed we will execute TVAC and random vibration testing. The TVAC profiles will be chosen to meet the requirements of the GSFC General Environmental Verification Standard (document # GSFC-STD-7000). The profiles for the initial random vibration testing will be chosen to envelope the actual flight requirements for the CALIPSO, ICESat-1 and ICESat-2 missions.

2. Laser Transmitter for the Optical Autocovariance Wind Lidar

Ball Aerospace and Technologies Corporation was funded by the NASA Earth Science Technology Office to build an upgraded version of their original Optical Autocovariance Wind as part of the ATHENA-OAWL Venture Technology program [7]. As part of that program, Fibertek was funded to design and build and upgraded version of the original OAWL laser that would meet the < 30 MHz linewidth requirement for both the 532 nm and 355 nm outputs and still provide 355 nm pulse energies of >30 mJ at 200 Hz. Our updated design, shown schematically in Figure 4, accomplishes this goal by the addition of a second amplifier.

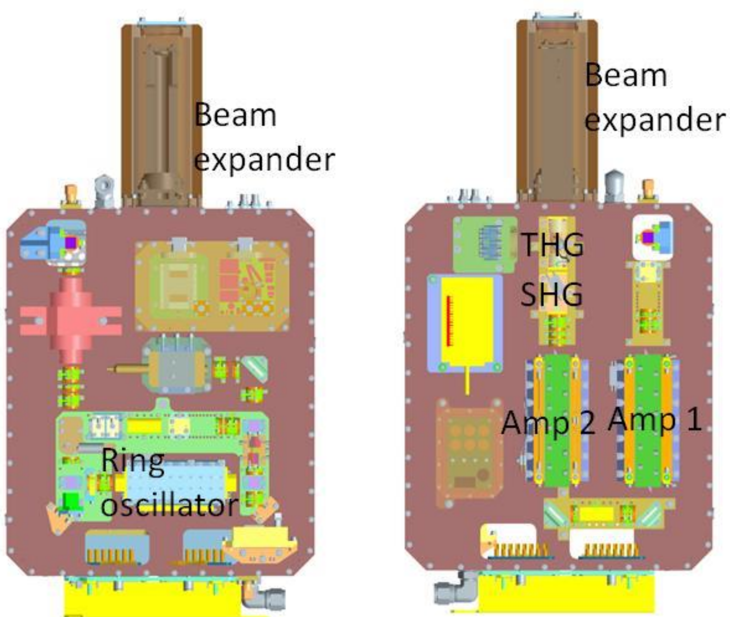

Figure 4. ATHENA OAWL oscillator (left) and amplifier (right) compartments

Performance testing of the laser, summarized in Table 2, shows that it met or exceeded all of the requirements except spectral purity, which is still quite high at 5,000:1.

Table 2. Performance of the ATHENA-OAWL Venture Tech Transmitter

Parameter	Specification	Measured Performance
Pump source	808 nm laser diodes	808 nm laser diodes
Cooling	Conductive	Conductive
Repetition rate	200 Hz	200 Hz
Seeding	Ramp & fire injection seeding	Ramp & fire injection seeding
Seeding eff.	>99% seeded and meeting spectral purity	>99.99% seeded
Mode beating	Intensities increased <1.5X when not fully seeded	No unseeded pulses observed
532 nm spectral purity	>10,000:1	>5,000:1 (1104 I2 line)
Pulse energies	30 mJ @ 355 nm 20 mJ @ 532 nm 20 mJ @ 1064 nm	35 mJ @ 355 nm 24 mJ @ 532 nm 41 mJ @ 1064 nm
Linewidth	< 30 MHz @ 355 nm and 532 nm	532 nm – 26-28 MHz 355 nm – 26-28 MHz
Energy stability	± 10% from average (3σ)	532 nm - ± 2.6% (3σ) 355 nm - ± 1.7% (3σ)
Pulse width	>15 ns @ 355 nm and 532 nm Goal of > 20 ns, not to exceed 100 ns	532 nm - 28 ns 355 nm - 33 ns
Beam quality	532 nm - < 1.4 mm-mrad 355 nm - < 1.4 mm-mrad	532 nm - 1.14 mm-mrad in X, 1.13 mm-mrad in Y 355 nm – 1.21 mm-mrad in X, 1.05 mm-mrad in Y

3. Acknowledgements

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4. References

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