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3-Year-Program of 10W-Class Space-Borne Q-sw Laser Technology: Development of Entry Model for Earth Observation

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***Abstract*—Laser/LIDAR remote sensing technologies can satisfy a variety of measurement and operational requirements. Specifically lasers for LIDAR and its applications. These measurement techniques are finding uses in several earth science areas, including trace gases, water vapor, aerosols and clouds, wind speed and directions, oceanic mixed layer depth, ice sheet, vegetation canopy height, and others. Much of these sciences have been performed over the past decades using lasers, the measurements have been performed from the ground to aircraft. Improvements of knowledge in above science areas require further advances for not only higher spatial and temporal coverage by transport model (e.g. AGCM) but measured (NOT estimated) vertical profile by the space-based LIDAR instrument.**

In 2011, JAXA collaborated with NICT and RIKEN started a new cross-sectional 3-year program to improve the developing reliable, high beam quality, efficient laser mainly in the critical 1-micron wavelengths. This laser can be used for efficient frequency conversions devices such as second and third harmonic generation and optical parametric oscillation/generation and a variety of elements common to all measurement techniques, which includes heat rejection using high thermal conductivity materials, laser diode life time and reliability, wavelength control, and suppression of contamination control. The program has invested in several critical areas, including advanced laser transmitter technologies to enable science measurements (tree canopy, aerosol distributions, tropospheric trace gases, and wind vector), improvement of knowledge for space-based laser diode arrays, Pockels cells, advanced nonlinear wavelength conversion technology for space-based liars. Final goal is aim to realize 15 watt or more over class Q-switched pulse laser over 3-year lifetime.

I. Introduction

The lasers and LIDAR techniques in remote sensing has been proven beyond questions over the years. Measurements from the ground-based and from airborne are widely used and are valuable tools for understanding the earth environment. LIDAR techniques have been used to measure atmospheric species, profile winds, and develop high resolution topographical forest and ice sheet maps. An orbiting space platform has a wide view, can cover hundreds of kilometers per hour, and has access to the fully vertical profile [1], [2]. Space based LIDAR missions have generated detailed profile of atmosphere and elevation of Earth, Moon, and other planets. However, there have also been serious issue for longterm operation on space environment due to the generally developing knowledge (e.g. laser induced damage caused by contamination). This is even resulted in failures of laser transmitter, become main reason for deselected missions such as former aborted Japanese LIDAR mission [3].

In 2011, the JAXA started a cross-sectional 3-year program to improve the reliability for lasers in space. This work is being conducted jointly by National Institute of Information and Communications Technologies (NICT) and RIKEN. This paper describes an outline of our study.

II. Issue of lasers in space

The ground based and airborne laser systems can be seen on many LIDAR applications, and they are well suited for longterm operation with little maintenance over the lifetime of their systems. Any laser systems in space are out of the range to maintenance an instrument, except for the International Space Station and the Hubble Space Telescope.

We are currently focused on the following targets for lasers in space, 1) rigid optics and instrument for launch impact, 2) thermal load control for high power laser, 3) knowledge of ”bad actor” contamination and suppression, 4) improvement of knowledge of laser diodes (LD) and optics for longterm operation.

The first issue for space instruments is the launch itself. JAXA has been launching delicate optical instruments, however, the aligned laser cavity are required more robust to the launch impact than most telescopes.

LIDAR transmitters in space will require high average output powers. This requirement is result from competition with background solar radiation, weak aerosol and molecular scattering signal, lower concentration of the chemical species. Current and planned laser transmitters are shown in Fig. 2, we are aimed of 15 class or more over Q-sw laser transmitter for future space LIDAR missions. A high power laser transmitter will result in concentrated exhaust heat. Ground based and

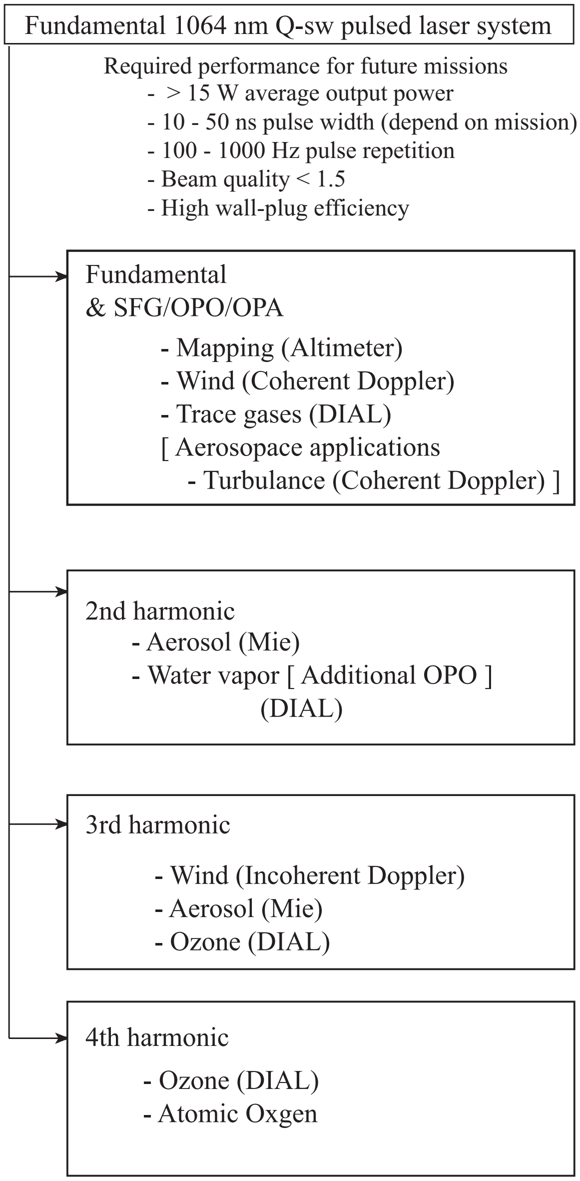

Fig. 1. Expected missions with high-end performance LIDAR.

airborne laser system can remove the heat from laser head with chilled water loop. Same cooling methods are impractical due to the weight and issue pumping fluids in zero gravity environment. To develop techniques for transferring heat from a compact laser on the spacecraft is faced to additional issue. The vacuum environment increases the difficulty of removal heat due to the loss of the heat transfer from the air.

The vacuum in space increases serious risk of contamination, which decreases laser induced damage threshold of coatings, although the damage threshold of the anti-reflection or high–reflection coatings has been increased by progress of techniques. Adhesives, lubricants, electrical insulations and number of other material used in the instrument will generate out gas in vacuum environment. The out gassed material can deposit on the laser optics and absorb laser energy,

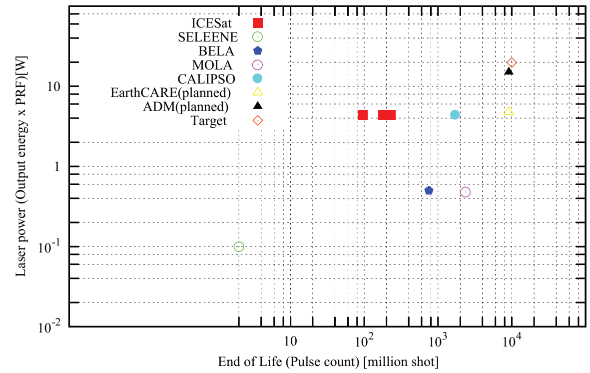

Fig. 2. Power and end of life of laser transmitter for current and planned space borne LIDAR system.

which cause serious damage of the optics. Once the optics are damaged, the LIDAR performance will be dramatically degenerated. This results in complete loss of a mission.

III. Reliability

Almost all of issues consist of reliability of materials, manufactured products process and handling during the build, verified test, and integration of instruments. A high peak power QCW LD stack as the pumping source is one of the most important reliability factors. Supposed mission lifetime is currently expected greater than 3-year, lifetime of LD with 100–Hz operation must be grater than 9×10^9 shots. We have set up LD stacks to test their reliability under atmosphere. LD stacks from three vendors have been tested optical output power versus current measurements with derating power (60% – 80%), thermal image and spectrum profile of the LD stacks during operating. In addition to the LD stacks, the nonlinear optical materials have been subjected to radiation test that is total ionizing dose effects test, high-energy radiation (proton) irradiation test. LD stacks are expected to be robust for both radiations, while most non-linear materials are required attention to radiation darkening.

Outgassing contamination is one of the careful factor for lasers in space because it cannot eliminate even if the bake out process after several days with a hundred degree Celsius are performed. This is because the resulting catastrophic damage described above. Many studies that indicated impact of contamination on laser operation on high vacuum environment were reported about UV wavelength region [4], [5]. Therefore, we are aimed at improving impact of contamination on laser in space and identify ”bad actor” materials in IR or visible wavelength.

IV. Laser development

A. Set up of oscillator

The fundamental pulse laser cavity design for the 100–Hz operation is depicted in Fig. 3. A resonator length of cm is chosen to obtain pulse durations of less than 10 ns. for damage threshold reasons in the further beam propagation. The distance between the surface of the end retro-reflector

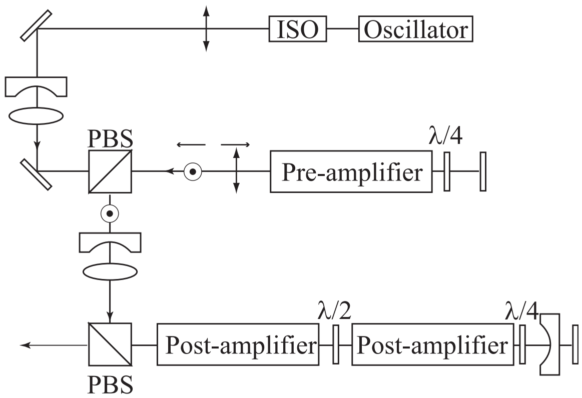

Fig. 3. Schematics of the laser system.

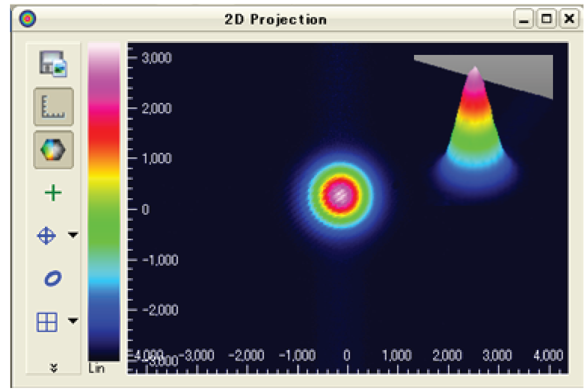

Fig. 4. The beam quality of testbed laser output at energy of 20 mJ, 15 ns.

and the first principal plane of the rod is 11 cm. The surface of the retro-reflector is polished and has a anti-reflection coating (reflectivity of less than 0.25%), whereas the output coupler has a reflectivity of 70%. To achieve dynamical stable operation, a radius of curvature of the output coupler for the 100–Hz operation was decided to suppress of a thermal lens effect. A twisted mode arrangement with two quarter-wave plates around the laser rod is realized to prevent spatial hole burning in the laser rod, which is an obstacle for optional single-frequency operation. The oscillator is Q-switched by a Pockels cell.

The oscillator is pumped with three diode stacks arranged in a threefold geometry around the Nd:YAG crystal. The pumping LD pulse has a length of 200-250 μs. The beam diameter of the TEM_{00} mode in the rod amounts to 0.75 mm in both the 100–Hz. The testbed supplies multi-frequency pulses with a duration of 15 ns (FWHM) and oscillate 20 mJ of pulse energy. The beam quality was measured to embody an M^2 of 1.3 in both transverse directions as shown in Fig. 4.

B. Amplifier module

All pumping chamber are LD pumped and conductive cooled. The pumping diode bars can achieve peak powers of 150 W. The gain materials are pumped in a triangle geometry. The pumping configuration of the pre–amplifier and post-amplifier is also a threefold geometry as same as the oscillator. The pre–amplifiers have Nd:YAG/Nd:YAG ceremics rods with a 6–mm diameter and an 35-mm pumping length and a doping concentration of 0.6 at.%. They are pumped by 9 diode stacks (27 diode bars), it can operate a full peak pump power of 4 kW. The post-amplifier pair contain Nd:YAG/Nd:YAG ceramics of 6 mm $\times$ 45 mm with a doping level of 0.6 at.%. They are pumped by 12 diode stacks (36 diode bars), each resulting in a full peak pump power of 5.4 kW. All the diode bars are included fast-axis collimation lenses. In the MOPA system discribed here, we operate the LD stacks with a derating power and duty ratio to protect . The slope efficiency of the post–amplifier and pre–amplifier are expected to 40%.

A large number of diode stacks is required to achieve pulse energy in the joule-level due to the limited lifetime of the upper laser level in Nd:YAG of 230 μs and the full peak power of the diode stacks of 450 W. We decided to set up the post-amplifiers in two pairs with double pass regime, the pre-amplifier in single module. Especially post–amplifiers generate a lot of exhaust heat compared with other modules and have to be compensated for thermally induced birefringence. Transversal thermal gradients in laser rods are causing refractive index changes in radial and tangential polarization directions (birefringence). Therefore they lead to depolarization and bifocusing. The birefringence can be compensated with a λ/2 plate in-between of two identically pumped rods [7]. With this combination the thermally induced optical path length differences caused by the first laser rod can be compensated in the second one and vice versa only by interchanging the radial and tangential polarizations. In order to achieve efficient birefringence compensation, the planes of maximum thermal gradient are imaged onto each other, a symmetrical beam propagation through two positioned laser rods that are as close to each other as possible. In front of the post–amplifier the lenses serve to expand the beam for the 6–mm rods. Consequently, the beam propagation was designed for symmetrical passage through the post–amplifiers.

V. Conclusion

Based on prior experiences of former MDS mission, corss-sectional 3-year-program have conducted jointly by JAXA, NICT and RIKEN. By mitigating the key technology issue in longterm operating space borne lasers, we will expect to reduce the risk for future laser-available missions.

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