Development of airborne 2-μm coherent lidar for CO_2 and wind measurements

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1. Introduction

Wind profile is fundamental in many atmospheric phenomena. Most of the weather stations are on land, while the stations on the sea are very sparse. Present global three-dimensional wind data is not good enough to improve numerical weather prediction, the global climate model, and many other meteorological studies. Spaceborne infrared and visible imagers and microwave scatterometers can make wind measurement only at a specific altitude. The spaceborne Doppler lidar is one of the candidate sensors for the global wind measurements. The European Space Agency is implementing an incoherent Doppler wind lidar mission called 'ADM-Aeolus' to obtain global observations of wind profiles. National Institute of Information and Communications Technology (NICT) studied a 2-μm conductively cooled laser-diode-pumped Q-switched solid-state laser as one of fundamental technologies for spaceborne Doppler lidar and demonstrated a 460mJ output operating at 10 Hz during the first 5-year middle term program (FY 2001-2005). The NICT also made ground-based and airborne wind measurements with a small coherent Doppler lidar developed by the Coherent Technology, Inc. We made ground-based experimental wind measurements with the small coherent lidar and investigated the basic performance of the coherent lidar. The airborne experimental wind measurements were conducted in 2002, 2004 and 2006. We studied the algorithms required to compensate for the aircraft speed and extracted the Doppler-shifted frequency. During the second 5-year middle term program (FY 2006-2010), we developed a 2-μm laser power of 2.4 W (80 mJ, 30 Hz) as a next-generation laser of the developed laser. We developed a ground-based coherent 2-μm differential absorption/wind lidar for CO_2 and wind measurements [1-3]. Ground-based experimental CO_2 and wind measurements were made to investigate the performance of the developed coherent differential CO_2/wind lidar in 2008 and 2010. The coherent differential CO_2/wind lidar was used for slant and vertical CO_2 measurements for the GOSAT data products validation in 2010 and 2011, and it was also used to investigate various atmospheric phenomena in the boundary layer and the free troposphere. A new 5-year middle term program (FY 2011-2015) has started in April 2011. We started to develop an airborne system in April 2011. The first purpose in the program is to develop a reliable 2-μm laser and an airborne coherent lidar, the second purpose is to demonstrate CO_2 and wind measurements using the airborne 2-μm coherent lidar, and the third purpose is to develop algorithms for CO_2 and wind measurements. The new airborne 2-μm coherent Doppler lidar is a precursor system for a spaceborne coherent Doppler lidar and it is a very important step to realize a spaceborne coherent Doppler lidar. In the paper, we will describe current status of the new airborne 2-μm coherent CO_2/wind lidar.

2. Development of reliable 2-μm pulse laser for airborne CO_2/Wind measurement

It is a very important to develop a reliable 2-μm Q-switched pulse laser for airborne lidar. In order to realize the reliable 2-μm Q-switched pulse laser, pumping laser head and laser alignment for a long cavity are critical and difficult issues. We made some pumping laser head and are evaluating the performance of each pumping laser head. The pumping laser head comprises a Tm,Ho:YLF laser rod, 12 InGaAs/GaAs laser diode arrays (=4 diode arrays x 3 parts), light guides, and copper heat sinks, and it is installed in a vacuum container. Each laser diode array is water-cooled to 12 °C. The Tm,Ho:YLF laser rod is conductively-cooled to about -80 °C. Outputs of each 4 laser diode array were tested before installing into the pumping laser head. The c-axis of Tm,Ho:YLF laser rod is carefully installed into the pumping laser head to be vertically aligned. The performances of each the pumping laser head are evaluated by using Fabry-Perot laser cavity (Figure 1): (a) relation between LD input energy and Tm,Ho:YLF laser output energy, (b) excitation distribution with changing LD temperature, and (c) polarization during lasing. Data of the relation between LD input energy and Tm,Ho:YLF laser output energy were obtained before and after random vibration tests. Figures 2(a) and 2(b) show pictures of random vibration tests under the two conditions of (a) the pumping laser head alone and (b) the vacuum container installing the pumping laser head. Conditions of the random vibration were determined by taking considerations of

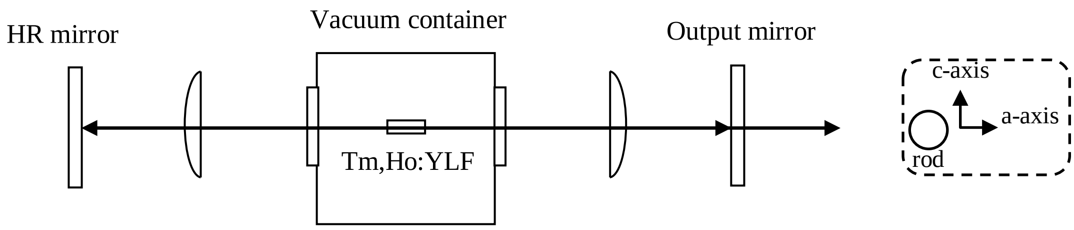

Figure 1 Block diagram of Fabry-Perot 2-μm laser cavity.

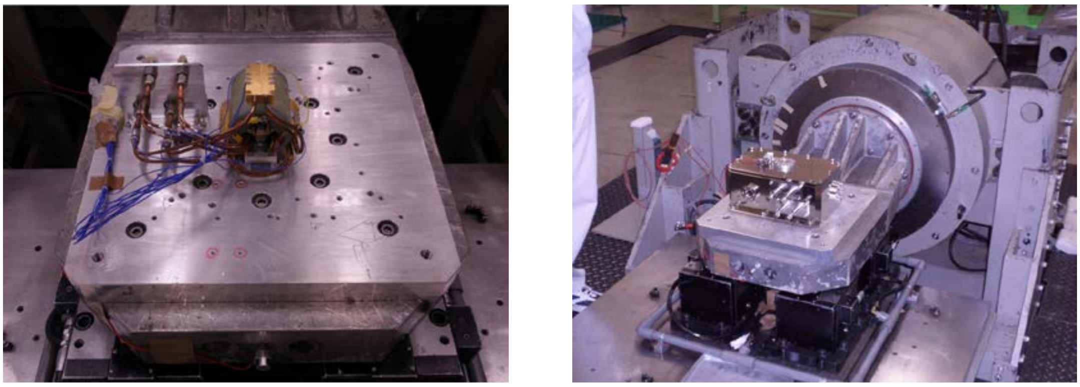

Figure 2 Random vibration test: (a) pumping laser head and (b) vacuum container installing the pumping laser head.

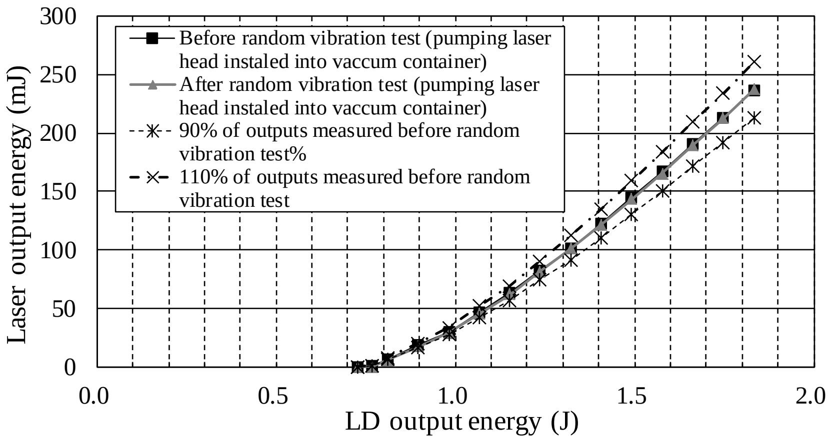

Figure 3 Fabry-Perot 2-μm laser output energy before and after random vibration tests.

vibrations of a supposed aircraft (Gulfstream II). There was no clear difference in the laser outputs before and after random vibration tests (Figure 3.). The relations between the input energy of laser diode arrays and the output energy of Fabry-Perot 2-μm laser were tested for various pulse pumping repetition with changing pumping durations of laser diode with consideration of spatial resolution of airborne experiments and future spaceborne missions. Figure 4 shows an example of the relation between the two energies. The result indicated that we can operate the 2-μm Q-switched pulse laser for at the pulse repetition frequency of up to 50 Hz.

Basic configuration and specifications of the airborne 2-μm coherent CO_2/wind lidar is the same as the ground-based 2-μm differential absorption and wind lidar. The specifications of the airborne 2-μm coherent CO_2/wind lidar are listed in Table 1. Figures 5 shows a block diagram of the Q-switched pulse laser and optical receiver. A beam of the Q-switched pulse is reflected six times in the ring cavity to realize a compact airborne lidar. The tuneable on-line wavelength is generated by laser frequency offset technique. The on-line wavelength can be set in the range of 2051.002 to 2051.058 nm. The wavelength of the off-line laser is set at 2051.250 nm, which is controlled only by a PZT. The on- and off-line lasers are alternately switched every 1 shot. The backscattered signal from atmosphere is measured by the heterodyne detection on an InGaAs PIN photodiode. The heterodyne detection is operated under the shot noise limited condition (9 dB). A balanced InGaAs photoreceiver (DET_2) is used for monitoring the frequency of the outgoing laser pulse. The outputs of the detectors are digitized by using 14-bit analog-to-digital converters (Signatec PCI14400). The power spectra of the laser pulses (on-line and off-line pulses) and backscattered signals are obtained by the fast Fourier transforms. The housekeeping data from the inertial measurement unit and the global navigation satellite system is given by the Position and Orientation System (POS AV 610), and it is saved in the data storage.

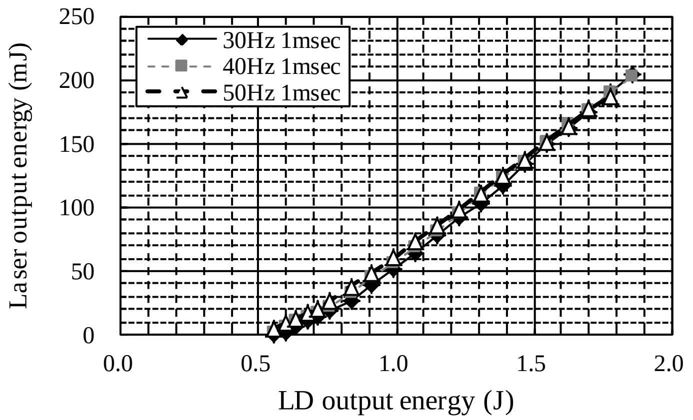

Figure 4 LD output energy versus Fabry-Perot 2-μm laser output energy.

Table 1 Specifications of airborne 2-μm coherent CO_2/wind lidar

Transmitter	
Laser	Tm,Ho:YLF
Wavelength	2051.002–2051.058 nm (On) 2051.250 nm (Off)
Pulse energy	50–80 mJ/pulse (Target)
Pulse width	150 ns (FWHM)
Pulse repetition	> 30 Hz
Polarization	Circular
Receiver	
Telescope type	Mersenne off-axis
Diameter	10 cm
Magnification	10 x
Detector	InGaAs-PIN photodiode
DET_1	Balanced InGaAs-PIN photodiode
Resolution	14-bit A/D conversion
Sampling frequency	400 MHz

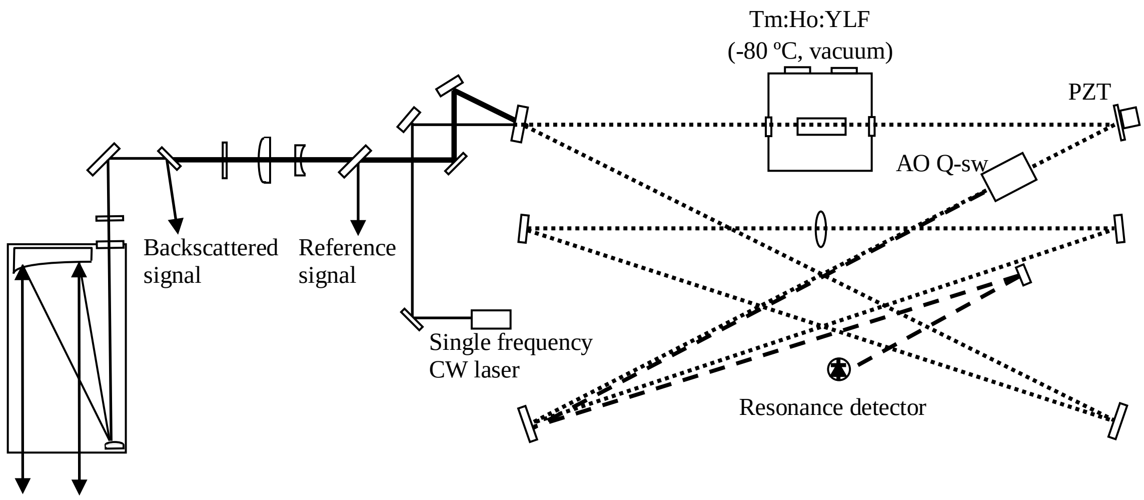

Figure 5 Block diagrams of the Q-switched pulse laser and optical receiver.

3. Summary

The NICT is developing the new airborne 2-μm coherent Doppler lidar for CO_2 and wind measurements. Current status of the airborne 2-μm coherent Doppler lidar is described in the paper. Japanese spaceborne lidar mission programs for the purposes of the atmospheric science have not been planned since the Experimental Lidar in Space Environment (ELISE) mission program. Since the ELISE mission program, the iss-jem (International Space Station (ISS)-Japanese Experiment) Lidar for Observation of Vegetation Environment is proposed in Japan. The ideas on the Japanese earth observation mission program after 2020 are discussed in the three fields: land, ocean and atmosphere. The NICT promotes the spaceborne Doppler lidar in the various areas. In order to realize the future spaceborne lidar mission program, it is very important not only to develop the airborne 2-μm coherent lidar but also to demonstrate airborne CO_2 and wind measurements with high accuracy.

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