Research and development for future space-based Doppler Wind Lidar

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Abstract: National Institute of Information and Communications Technology (NICT) has developed technologies for a 2-µm coherent lidar since 2001. The forth middle term research program began in April 2016 at NICT. Main objectives of the lidar project are to develop 2-µm key technologies and instruments for a future space-based coherent Doppler wind lidar (CDWL), to investigate measurement performance using a space-based coherent Doppler wind lidar simulator, and to quantitatively assess potential impacts on numerical weather prediction using results of the space-based CDWL simulator. In the paper, we introduce research and development of the 2-µm key technologies planned during the middle term research program.

1. Introduction

NICT developed a 2-µm coherent differential absorption/Doppler wind lidar for CO_2 and wind measurements [1-2] and a coherent lidar for airborne experiment during the last middle term research program. Japan Aerospace eXploration Agency (JAXA) is developing a new type of satellite for future Earth observation missions and it is looking for a candidate mission after the test flight of the satellite. NICT, Tohoku University (TU), the University of Tokyo (UT), Meteorological Research Institute (MRI), and JAXA organized a working group for a future space-based CDWL and are studying the feasibility from the technical and scientific viewpoints to realize the future space-based CDWL [3-5]. NICT started the new middle term research program to develop key technologies for the future space-based CDWL. In the paper, we present research and development for future space-based CDWL.

2. 2-µm laser system

A CDWL requires a single-frequency 2-µm Q-switched laser. A reliable single-frequency continuous-wave (CW) laser is critical for the single-frequency 2-µm Q-switched pulse laser and the heterodyne detection. The single-frequency CW laser needs to have a long coherent time, which means that it does not change the frequency during the round-trip time between the CDWL and the target atmosphere. Current technical requirements for the future single-frequency 2-µm CW laser are TEM_{00} mode, wavelength tuning, output of >30 mW, long frequency stability, long-term output power stability, linear polarization, and low frequency jitter. Figure 1 shows spectra of photoluminescence for (left) a semiconductor laser with quantum-dot structures and (right) a Tm-doped fiber amplifier (TDFA). The peak wavelengths of the semiconductor laser and the TDFA are 1980-nm and 1950-nm. The two spectra are very wide. We can confirm the photoluminescence from both the semiconductor laser and the TDFA at a target wavelength of 2.05 µm. We need to further optimize characteristics of the semiconductor laser and the TDFA.

Target pulse energy of the single-frequency Q-switched laser is 125 mJ operating at a pulse repetition frequency of 30 Hz. Two candidate laser systems are discussed for the future space-based laser: one oscillator configuration, and MOPA (MOPA: Master Oscillator Power Amplifier) configuration (Figure 2).

The laser rod of the single-frequency 2-μm Q-switched laser developed at NICT must be cooled down to -80 °C to achieve pulse energy of 80 mJ. Experiments indicated that, if a Tm,Ho:YLF laser rod were cooled lower than -100 °C, the one-oscillator-configuration 2-μm laser could achieve 125 mJ per pulse. MOPA configuration were more compact than the one-oscillator-configuration 2-μm laser, MOPA configuration 2-μm laser would be better approach. The TIT laser simulator indicates that the MOPA-configuration 2-μm laser could emit a pulse of 125 mJ at a laser rod temperature of -40 °C: a target pulse energy of the master oscillator is about 50 mJ, and a target gain of the power amplifier is about 3.

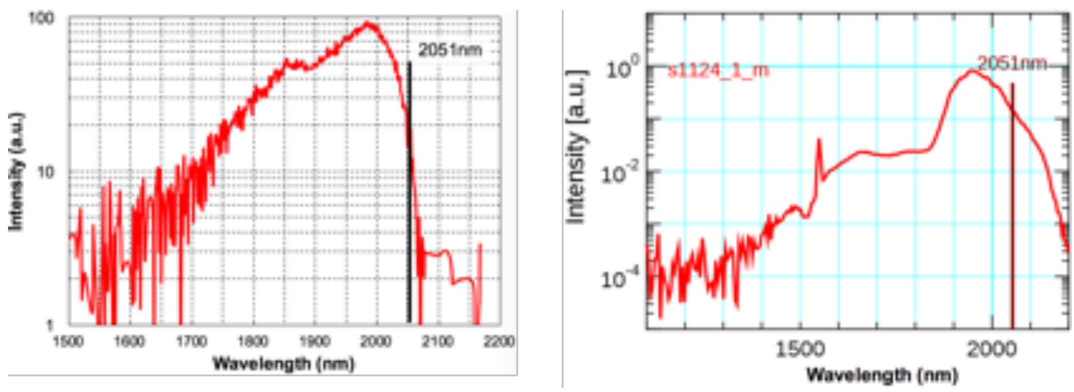

Figure 1. Photoluminescence from (left) quantum-dot laser and (right) Tm-doped fiber amplifier.

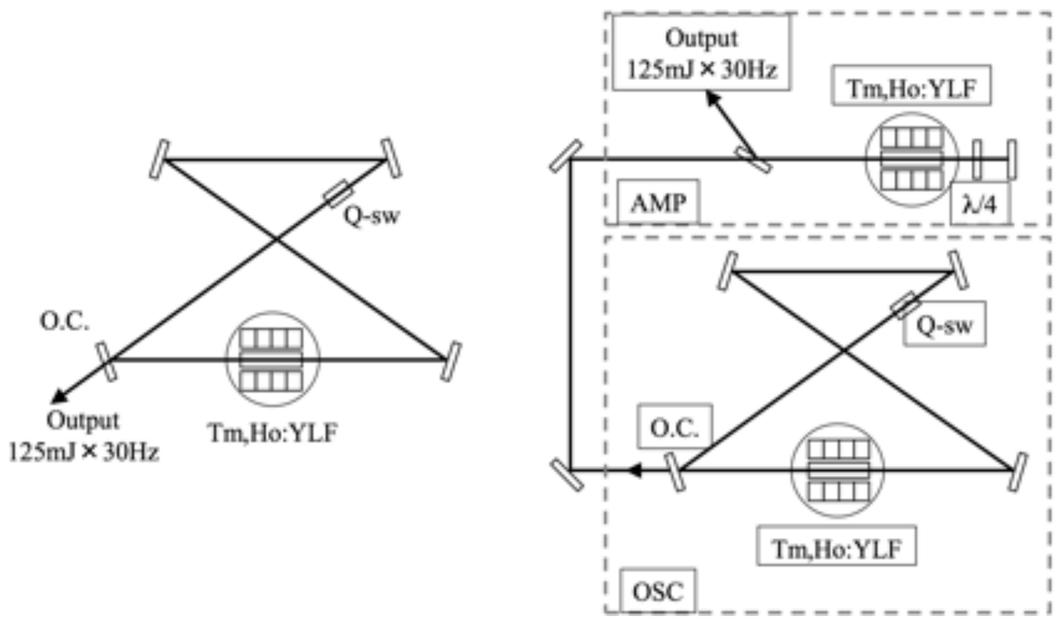

Figure 2. Tm,Ho:YLF laser: (left) one-oscillator configuration, and (right) MOPA configuration.

3. Coherent receiver

A coherent receiver requires a telescope with diffraction-limited performance. The telescope must be designed to avoid wavefront aberrations. The current concept of the afocal telescope is coaxial system with a beam-expanding collimator and a receiving telescope, and the future space-based CDWL uses two fixed off-axis telescopes in order to observe two line-of-sight wind speeds. JAXA is developing a new satellite with ion propulsion technologies developed in the past space missions. The new satellite will fry in a circular orbit at attitudes of 180-270 km at a speed of about 7.8 km/sec. We assume that the horizontal wind speed is 100 m/sec. A speed of 1 m/sec corresponds to about Doppler-shifted frequency of 1 MHz at wavelength of 2 µm. The Doppler-shifted frequency at the maximum horizontal speed at 2 µm is assumed to be 7.9 GHz (=7.8 GHz + 0.1 GHz). The laser pulse will be sent into the atmosphere at the azimuth angles of 45° and 135° and at the nadir angle of 35°. The Doppler-shifted frequency is about 3.2 GHz. A high-speed detector with a bandwidth of >3.2 GHz is required for the space-based CDWL wind measurements. The Doppler-shifted frequency due to the satellite speed must be compensated by hardware-based onboard frequency calibration. Analog-to-digital (AD) conversion from an analog signal to a discrete signal is used in data processing. Both sampling frequency and sampling points of an AD converter determine the frequency and range resolutions in the CDWL wind measurement. There are some space-qualified, high-speed, and high-resolution AD converters (e.g., Texas Instruments ADS5463-SP and ADS5474-SP). With a sampling frequency of 400 MHz, the frequency resolutions for the 4096-point FFT and the 256-point FFT are 0.10 and 1.56 MHz, respectively, and the 256-point FFT corresponds to a range resolution of 96 m. The concept of the space-based CDWL is summarized in Table 1. An InGaAs detector is one of candidate detectors. Electrical characteristics of the InGaAs detector might be affected by proton radiation. The space-qualified high-speed detector must be designed and fabricated to meet the orbital type and altitude of the new satellite.

Table 1. Concept of future space-based CDWL.

Wavelength (µm)	2.05
Pulse energy (mJ)	125
Pulse repetition frequency (Hz)	30
Effective telescope diameter (cm)	40
Number of laser directions	2
Total coherent receiver efficiency	0.07
Sampling frequency (MHz)	400
Sampling point	256
Nadir angle of observation direction (°)	35
Azimuth angle of observation direction (°)	45, 135
Target vertical resolution (km)	Altitude 0-3 km: <0.5 Altitude 3-8 km: <1 Altitude 8-20 km: <2
Target horizontal resolution (km)	<100

4. Summary

JAXA is developing a new type of satellite for future Earth observation missions and planning to launch the test satellite in FY2016. JAXA is looking for a candidate Earth observation mission after the test flight. The Japanese working group for the future space-based CDWL is studying the feasibility from the technical and scientific viewpoints to realize a future space-based CDWL. NICT started the new middle term research program and it is studying the feasibility of 2-µm key technologies for the space-based CDWL. Preliminary results of the 2-µm transmitter were presented in the paper. Approaches for development of the detector and signal processing were introduced in the paper. NICT intends to continue development of 2-µm key technologies meeting the requirements for the space-based CDWL.

5. Acknowledgements

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6. References

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