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1.5-μm Er,Yb:Glass Coherent Lidar

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1. Introduction

A coherent lidar is an attractive sensor for atmospheric observation because it can measure wind velocity even in clear air conditions. It is needed eye-safety same as other laser equipment used in the field. As the coherent lidar in eye safe wavelength (>1.4-μm wavelength), one using 2-μm pulsed laser such as Ho,Tm:YAG and Tm:YAG laser is reported.[1, 2]

Compared to 2-μm, the wavelength of 1.5-μm has a ten times higher maximum permissible exposure for human eyes. In addition, optical fiber components and devices for use in optical fiber communication are easily available at this wavelength. Therefore, a coherent lidar, which use 1.5-μm pulsed laser, is more attractive than a 2-μm coherent lidar. To our knowledge, a 1.5-μm coherent lidar operation to measure wind velocity hasn't been reported yet. That because a single frequency 1.5-μm laser that had both high repetition rate and enough power for coherent lidar wasn't provided. Nd:YAG + OPO [3] and injection-seeded, flash lamp pumped Er:Glass laser [4] for 1.5-μm coherent lidars were recently reported and are now under development.

We are developing a 1.5-μm coherent lidar using an injection-seeded, LD pumped Er,Yb:Glass laser. In our system, a microchip laser made of Er,Yb:Glass is used for a seed and a local source.

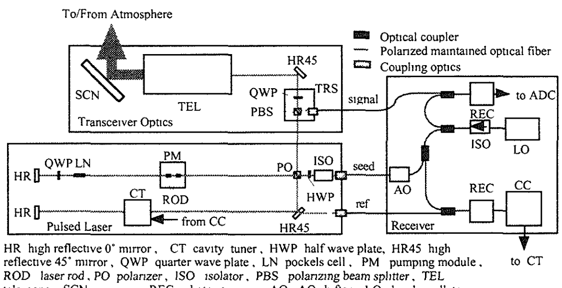
In this paper we describe our system and primary data of measured echo of aerosols.

2. System description

A block diagram of the developed 1.5-μm coherent lidar is shown in Fig. 1. Optical couplers divide the output of a local oscillator in three beams. Two of the beams are used in heterodyne detection. The another one is used as a seed beam in injection seeding of the pulsed laser, after its frequency is shifted by an intermediate frequency (f_{IF} =85MHz) using an acousto-optics (AO) frequency shifter.

The transceiver optics is co-axial. Output beam from the pulsed laser is expanded by a telescope (TEL) and radiated into the atmosphere using a scanner (SCN). The effective diameter of the telescope is 60-mm. In a T/R switch, the received signal is separated from the transmitted beam and is put into a polarized maintained optical fiber. It is mixed with the local beam at the photo receiver to generate the heterodyne beat signal. The beat signal is sent to an AD converter.

The polarized maintained optical fiber is used in order to make the optical arrangement easily in the receiver and to utilize a small, high reliability optical component for the optical fiber communication.



HR high reflective 0° mirror, CT cavity tuner, HWP half wave plate, HR45 high reflective 45° mirror, QWP quarter wave plate, LN pockels cell, PM pumping module, ROD laser rod, PO polarizer, ISO isolator, PBS polarizing beam splitter, TEL telescope, SCN scanner, REC photo receiver, AO AO shifter, LO local oscillator, CC cavity controller, ADC AD converter, TRS T/R switch

Fig.1 Block diagram of the 1.5μm coherent lidar.

2.1 The local oscillator (LO)

A microchip laser is used as a local oscillator. It was built in a small module by utilizing the technology of LD modules for optical communication. The developed microchip laser module is shown Fig.2. The size of the module is 38.6x31.8x18.5mm^3. A schematic diagram of this module is shown in Fig.3. It consists of a pumping LD with a fiber lens, the coupling optics between the LD and an Er,Yb:Glass chip, a sapphire plate and an optical isolator. The output beam from Er,Yb:Glass chip is put into the optical fiber by a coupling lens. A TE cooler controls those temperatures. A 1-W class high brightness Al free InGaAs LD is used for pumping.

The thickness and the reflection of output surface of the Er,Yb:Glass chip were designed as 0.28-mm and 98.3%, respectively. The Er^{3+} ion concentration is $1x10^{20}$ cm^{-3} and the Yb^{3+} ion concentration is $1.5x10^{21}$ cm^{-3}. The Er,Yb:Glass chip was optically and thermally contacted to the sapphire plate with a transparent optics cement. As the sapphire plate is used for thermal spreader, heat removal from the Er,Yb:Glass chip is done along the optical axis of the microchip laser. The changes of output divergence with thermal lens effect are kept small by this method. Then, high coupling efficiency of the output into the optical fiber is maintained.

A microchip laser that uses an isotropic material for laser medium such as Er,Yb:Glass has dual polarized modes that are orthogonal.[5] The polarization dependent isolator not only reduces a back reflection but also extracts only one of the polarized modes for local beam.

Our microchip laser module has side mode suppression ratio more than 20-dB and a fiber coupled, single frequency output of 23.2-mW is obtained. The wavelength of output beam is 1.534-µm. By the self-delayed heterodyne method using a 91-km length optical fiber, the linewidth of 20.5-kHz was measured.

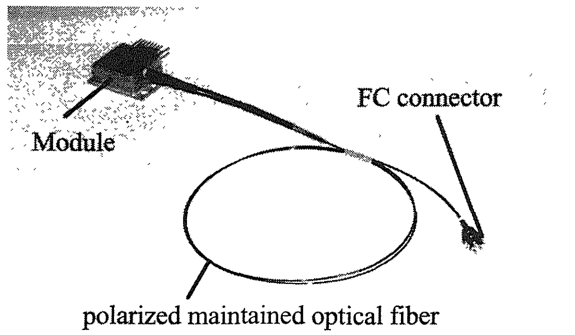


Fig. 2 The microchip laser module.

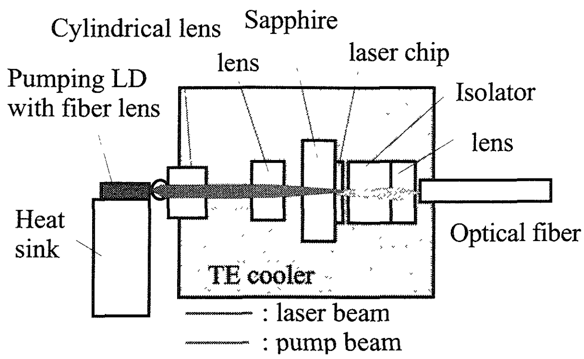


Fig. 3 Schematic diagram of the microchip laser module.

2.2. The pulsed laser

The laser cavity consists of two high reflective mirrors (HR). Each radius of curvature of those mirrors is 1-m. The cavity length is about 2-m. A $LiNbO_3$ Pockels cell was used for E/O Q switching. The seed beam from the microchip laser is injected into the cavity through the polarizer (PO). The pumping module, which was placed near the center of the cavity, consists of two Er,Yb:Glass rods, four five-stacked LD arrays and water-cooled heat sinks. Pump energy of these LDs is 740-mJ/pulse (0.975-µm wavelength) at 40-Hz repetition rate. PO radiates the output pulse from the cavity.

A cross sectional view and appearance of the pumping module is presented in Fig. 4 and Fig. 5. A pair of parallel lateral surface of each Er,Yb:Glass rod

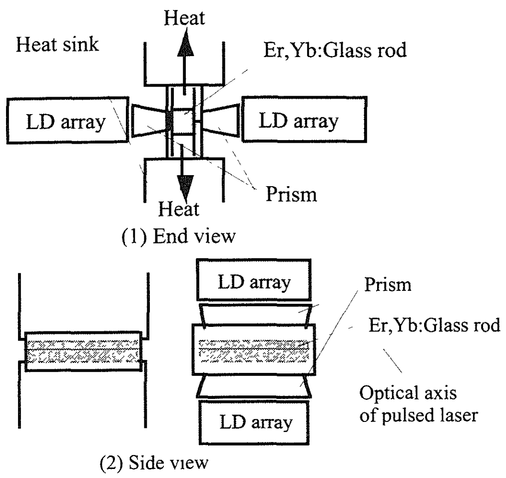


Fig. 4 Cross sectional of the pumping module.

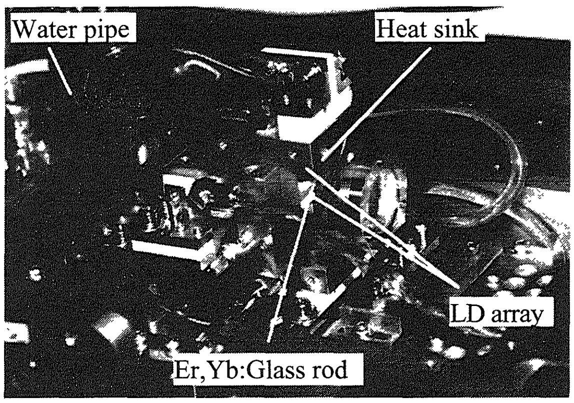


Fig. 5 Appearance of the pumping module.

is in contact with heat sinks and the rod is pumped from the other pair of parallel lateral surface by two LD arrays. In this geometry a bifocusing of thermal lens occurs as the heat sink removes the heat generated by pumping in the Er,Yb:Glass rod. Then, in order to compensate the bifocusing effect, the two Er,Yb:Glass rods are arranged in series along the optical axis of the pulsed laser and the lateral surfaces in contact with the heat sinks are intersected perpendicularly each other.

Er,Yb:Glass is a quasi-three-level laser. For this reason, half or more of the Er^{3+} ions must be excited for getting a gain. Accordingly, it is desirable to reduce the volume of Er,Yb:Glass rod in order to obtain a high-density excitation with the same pumping energy. To match this condition the Er,Yb:Glass rod was chosen as $1.2 \times 1.2 \times 10 mm^3$ and the Yb^{3+} ion concentration and Er^{3+} ion concentration are $1.5 \times 10^{21} cm^{-3}$ and $6 \times 10^{19} cm^{-3}$, respectively.

To adjust the cavity length a cavity tuner (CT) was developed. It has two roof prisms whose spacing is changed by a piezoelectric translator and controlled by a cavity controller (CC). A bit of output pulse power is taken out from the HR45 mirror, then used as a reference signal in order to get the control signal of the cavity tuner. The cavity controller changes the cavity length that the beat signal of the reference and local beams is to become constant frequency.

The output pulse energy with and without seeding at 40-Hz repetition rate is 4.0-mJ and 4.6-mJ, respectively. The pulse width of the seeded pulse is 244-ns. Power spectrums of the beat signal, which was measured during 10-minutes, and overwritten on one screen are presented in Fig.6. The seeded-pulse frequency is stabilized within ±5.7-MHz (standard deviation).

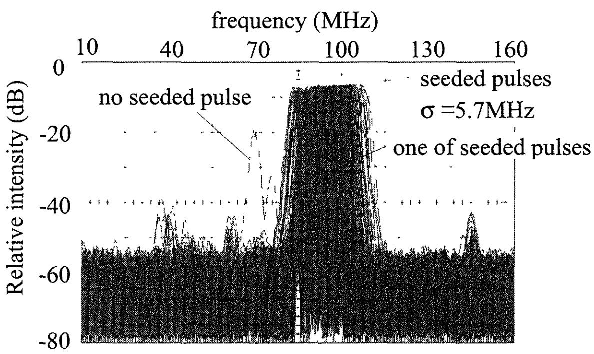


Fig. 6 Power spectrums of the beat signal.

3. Experimental results

The developed 1.5-μm coherent lidar was used for wind velocity measuring. The laser transceiver is shown Fig. 7. The lidar was positioned at about 5-m above the ground and it radiated laser pulses into the atmosphere with an elevation angle of 10°. The pulse energy was 2-mJ in this measurement.

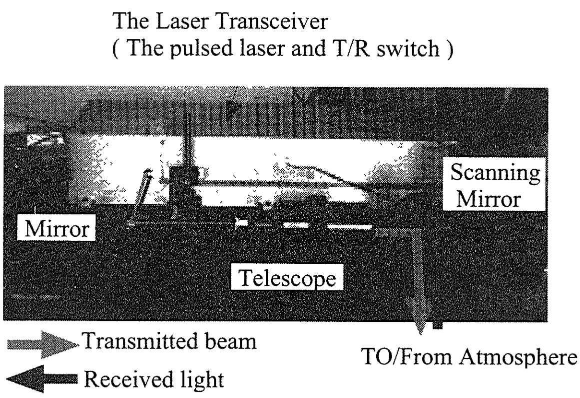


Fig. 7 The laser transciever.

The signal processing is as follows:

Range bin width: 30-m (200-ns)

Window: Hanning

Sampling frequency: 500-MSa/s

Frequency bin width: 488-kHz (0.37-m/s)

An example of the measurement is presented in Fig. 4. The result has an averaged frequency spectrum of received signals of 100 pulses. The calculated SNR using theoretical coherent lidar equation [6] is also shown in Fig. 4. Calculation parameters of Table 1 were used. It is considered that the differences between the measured and the calculated SNR at mid-range were caused by an insufficient adjustment of the transceiver optics. The diameters and phase front radii of the transmitted and the assumed backpropagated local beam were not sufficiently matched at the transceiver optics in this primary measurement. Readjusting them will improve the measured SNR.

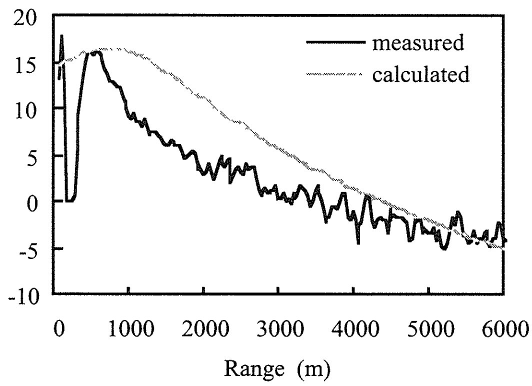


Fig.8 Measured intensity of the beat signal.

Table 1. Calculated parameters.

Laser Wavelength	: 1.543μm
Atmos. transmission	: 0.9/km
Aerosol Backscatter Coeff.	: $1x10^{-6} m^{-1} sr^{-1}$
Refractive index structure constant	: $3.3x10^{-15} m^{4/3}$
Detection efficiency	: 0.06
Beam Diameter	: 60mm
Focal Range	: 2000m
Pulse Energy	: 2mJ
Range Resolution	: 30m

4. Summary

We developed a 1.5-μm coherent lidar that incorporates an injection seeded, LD pumped Er,Yb:Glass laser for a slave laser and a microchip Er,Yb:Glass laser module for a seed and a local source. The laser radiates a single frequency, injection seeded pulse of 4.0-mJ at 1.534-μm wavelength with a repetition rate of 40-Hz. Experimentally we obtained the echo of aerosols to distances several kilometers by this 1.5-μm coherent lidar.

References

1. R. Targ et. al. : Appl. Opt. **35**, 7117 (1996).
2. S. Hannon and J. Thomson : J. Mod. Opt. **41**, 2175 (1994).
3. T. P. Gryson et. al. : Coherent Laser Radar , Vol.19, 1995 OSA Technical Digest Series (Optical Society of America, Washington DC, 1995), p.74.
4. A. J. McGrath et. al. : Appl. Opt. **37**, 5706 (1998) .
5. S. Taccheo et. al. : Opt. Lett. **20**, 889 (1995).
6. R. Targ, M. J. Kavaya, R. M. Huffaker and R. L. Bowles: Appl. Opt.**30**, 2013 (1991)