# 2-micron Laser Development for Wind and $CO_2$ Observations

Kohei Mizutani[1], Toshikazu Itabe[1], Shoken Ishii[1], Hironori Iwai[1], Kazuhiro Asai[2], Atsushi Sato[2], Hirotake Fukuoka[3], Takayoshi Ishikawa[4], Teiji Kase[5], and Tetsuo Shiina[6]
[1]National Institute of Information and Communications Technology, Tokyo 184-8795, Japan, mizutani@nict.go.jp
[2]Tohoku Institute of Technology, Yagiyamakasumi, Taihaku-ku, Sendai 982-8577, Japan
[3]Hamamatsu Photonics K.K., Shin-Miyakoda, Kita-ku, Hamamatsu, Shizuoka 431-2103, Japan
[4]Nippon Aleph Co., Komaoka, Tsurumi-ku, Yokohama 230-0071, Japan
[5]NEC Co., 1-10 Nisshin-cho, Fuchu, Tokyo 183-8501, Japan
[6]NEC Engineering Ltd., 5-22-5 Sumiyoshi-cho, Fuchu, Tokyo 183-8502, Japan

## 1. Introduction

2-micron eye-safe solid lasers doped with Tm and/or Ho are powerful tools for remote sensing of wind, $H_2O$ and $CO_2$ concentration[1]. We need 2-micron lasers for wind profile observations and $CO_2$ observations and have developed 100mJ Tm,Ho:YLF laser oscillator and 460mJ Tm,Ho:YLF laser amp[2,3]. These lasers are powerful and need much pumping light. Composite laser rod and 28 laser diodes, both of which are very expensive, are used. Moderate output compact lasers are more suitable for wind measurements and also for $CO_2$ DIAL measurements in mobile experiments. The area to be covered for the wind measurement is about 20-30km. The laser is also used for air-borne $CO_2$ DIAL instrument. We have developed a pulsed laser of moderate output of 50-100mJ at 20-30Hz for a $CO_2$ DIAL/Wind Doppler lidar system (Co2DiaWiL)[4]. Though the output capability is suitable to our objective, this laser is yet large in size as a mobile lidar system. Then, we started to develop a more compact laser. We will describe the present status of Co2DiaWiL and development of the new laser for a mobile lidar system. Moreover, we want to try other type of more powerful lasers for future project to extend the observation range and getting better accuracy.

## 2. Co2DiaWiL

Co2DiaWiL(Coherent 2-micron Differential absorption and Wind Lidar) has been developed. It was installed in a container with two axes scanner (Figure 1) and set on the roof of our laboratory. We made observations of wind profiles and $CO_2$ concentrations in the laser output of 50-80mJ at 30Hz there. The pulse width at this output level is about 150nsec. Even in the time of non-observation, the laser was almost continuously operated at

Figure 1 Picture of the inside of Co2DiaWiL

30Hz from Feb. 2010 to Mar. 2011 for stability and endurance test of the laser. Plane position indicator (PPI) scan data obtained in 3minutes is shown in Figure 2. Elevation was fixed at 2degrees. We could measure wind distribution in 30kmx30km area by PPI in this case. The non-colored area around the center of the figure indicates the unobservable direction by obstacles as buildings and trees. A

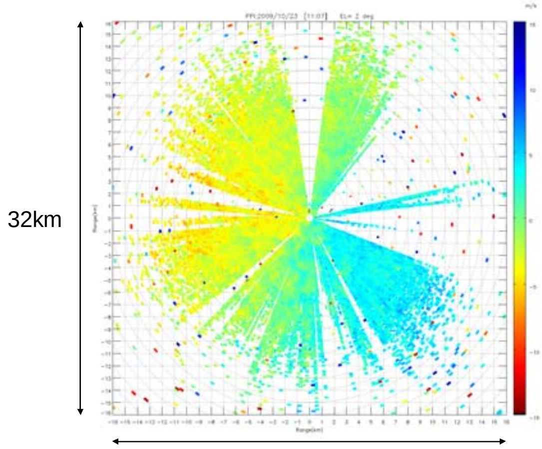


Figure 2. PPI measurements of horizontal winds (EL=2 degree)

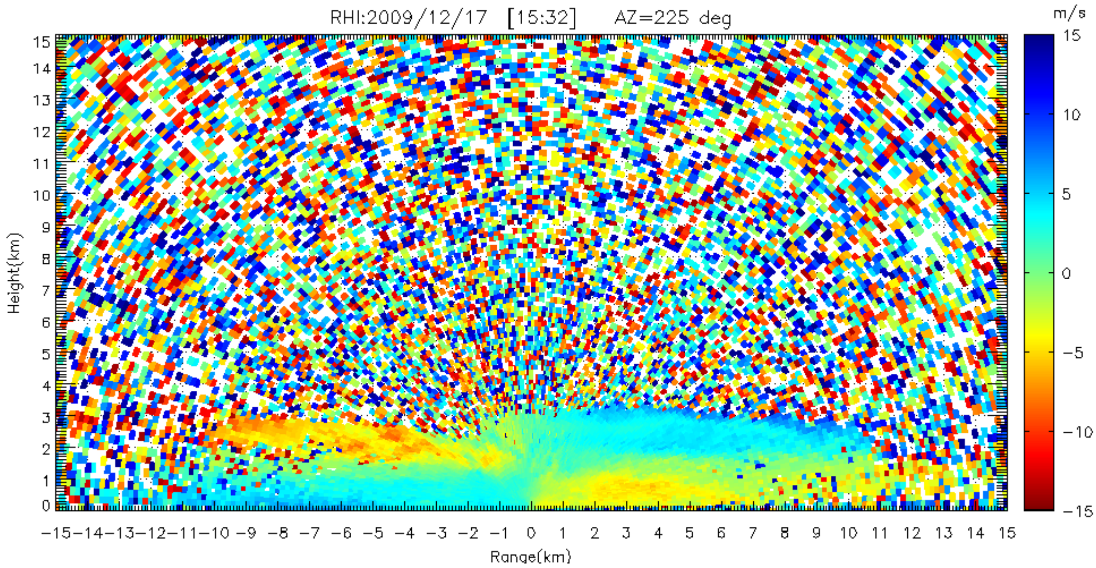


Figure 3 RHI measurement of winds (Az=225degree)

few km to sub-km small wind structures are seen in Figure 2. Range height indicator (RHI) scan data at an azimuth of 225 degrees is shown in Figure 3. Wind direction is changed around a height of 1km. We can examine the three dimensional wind structures by the combinations of these scans and measure horizontal wind up to more than 20km in a few minute.

## 3. Mobile lidar system

The optical components for Co2DiaWiL are set on a large optical table as shown in Figure 1. More compact and firm systems are needed for mobile experiments. Then, we are developing a compact $CO_2$ DIAL/Wind Doppler lidar system. The laser should be operated in 50-80mJ output at 30-50Hz. A similar type of a pumping module to Co2DiaWiL is set in a compact vacuum container (Figure 4). A 4mm diameter x 44mm length Tm(4%),Ho(0.4%): YLF rod is configured to be side-pumped from three directions by 12 laser diodes. The Tm,Ho:YLF rod is conductive-cooled down to about -80C from three Cu heat sinks through Indium thin film. The 12 laser diodes are also conductive-cooled to about 20C from other three Cu heat sinks. The central rod holder part is thermally separated from laser diode part in the outside of the pumping module. 792nm light from laser diodes pumps the laser rod through three quartz light guides between the three rod heat sinks. The pumping module was tested in a simple Fabry-Perot type resonator configuration. Reflectance of the output coupler was 60%. The rod was Tm(4%),Ho(0.4%):LLF in the first time. Long pulse and multi mode output power of about 200mJ was obtained at 30Hz (Figure 5). It is similar to that of Tm,Ho:YLF laser in Co2DiaWiL. Output was gradually increased up to the level of 200mJ, which means that good thermal contact is maintained between the rod and the heat sinks. When we changed the rod to Tm(4%),Ho(0.4%):YLF, the output is decreased. It is about 30% at LD current of 45A. Tm,Ho:LLF has been shown to be a little efficient laser crystal in the comparison with Tm,Ho:YLF[4,5]. We have confirmed it. We designed and made a trial laser for the

Figure 4 new laser head in a vacuum container

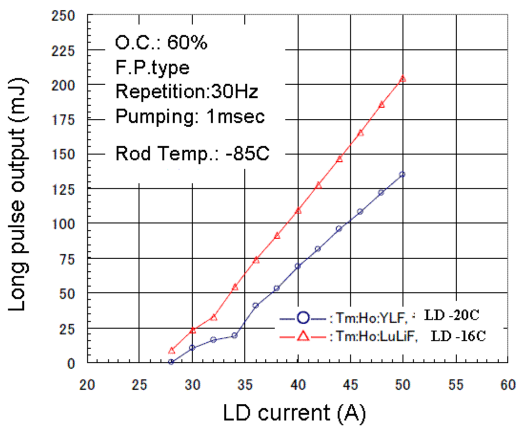


Figure 5 Long pulse output energy

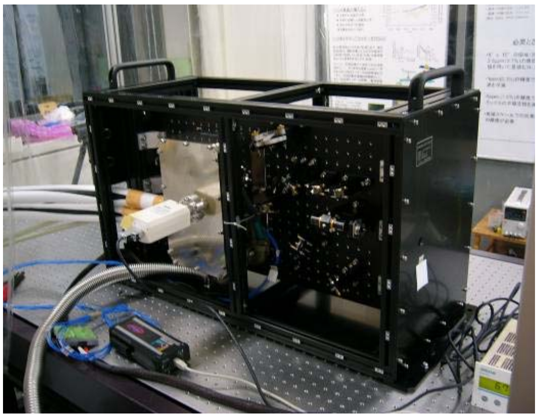

Figure 6 Trial laser for the compact laser

characterization of the compact laser. The ring resonator of a length of 3.8m is almost same as Co2DiaWiL, but more compact. The resonator with Q-switch and a mirror on piezoelectric stack for a ramp-and-fire mechanism is set on both sides of an optical breadboard of 660mm x 400mm (Figure 6). The laser is in test phase in laboratory.

## 3. Ho laser pumped by Tm fiber laser

Ho laser end-pumped by Tm fiber laser is potential configuration for high average power output. Pumping fiber laser light of 1.9-micron reduces the heat load to Ho laser rod which emits at 2-2.1-micron. Outputs over 20mJ at 1kHz was obtained with MOPA configuration[6,7] of Ho:YLF laser. High repetition laser up to 10kHz for $CO_2$ measurement with coherent detection was developed[8, 9]. We set up for the experiment of a Ho:YLF laser, which emits at 2.05-micron and will use for wind and $CO_2$ measurements. Our objective is 20-50mJ at 300Hz. Conductive-cooled laser rod of about 20C is used. Emission wavelength of Ho:YLF is suitable to $CO_2$ observation. However, thinking of ground based observation of wind, we may use other laser crystals because the round-trip transparency even at off line wavelength of 2.0525-micron is about 0.4 for a distance of 20km. One of other candidates of similar configuration for wind observation is Ho:YAG laser end-pumped by Tm fiber laser. Ho:YAG laser emits at 2.09-micron. This type of laser is also studied for OPO pump source and remote sensing[10, 11].

## 4. Conclusion

We have developed a ground-based $CO_2$ DIAL/Wind Doppler lidar system (Co2DiaWiL) with a conductive-cooled and laser diode pumped 2-micron laser. Observations of Line-Of-Sight wind velocity and $CO_2$ concentration are usually made in 50-80mJ output at 30Hz. Wind velocity measurements of 30kmx30km are possible in a few minutes at the off-line wavelength. Range of wind measurements may be extended, if we use other wavelength where the atmosphere is more transparent. We are now developing a compact mobile $CO_2$ DIAL/Wind Doppler lidar system using a similar design to Co2DiaWiL, but compact and small. The new pumping module with a Tm,Ho:LLF rod showed a long pulse output of about 200mJ at 30Hz. The rod has been changed to a Tm,Ho:YLF. The output is decreased by about 30%. After the evaluation of the laser, we will develop a compact lidar system. Ho laser pumped by Tm fiber laser are also studied. The laser will be used at relatively high repetition rate of 300Hz. The developed lasers are conductive-cooled, eye-safe and solid-state. Then, these are suitable for space-borne lidars.

## 5. References


1. Koch G. J., M. Petros, J. Yu, U. N. Singh, "Precise Wavelength Control of a Single-frequency Pulsed Ho:Tm:YLF laser", Appl. Opt., 41, pages 1718-1721, (2002)
2. Mizutani K., et al., "Development of Conductively Cooled 2micron Laser Oscillators", 23rd ILRC, *ISBN*4-9902916-0-3, pages 1037-1038, (2006)
3. Mizutani K., et al., "Development of Conductive Cooled 2micron Lasers", Pro. 13th Coherent Laser Radar Conference, pages 32-35, (2005)
4. Sudesh V., K. Asai, "Spectroscopic and diode-pumped-laser properties of Tm,Ho:YLF; Tm,Ho:LuLF; and Tm,Ho:LuAG crystals: a comparative study", J. Opt. Soc. Am. B, page 1829-1837, (2003)
5. Walsh B. M., N. P. Barnes, M. Petros, J. Yu, U. N. Singh, "Spectroscopy and Modeling of Solid State Lanthanide Lasers: Application to Trivalent $Tm^{3+}$ and $Ho^{3+}$ in $YLiF_4$ and $LuLiF_4$", J. Appl. Phys., 95, pp.3255-3271, (2004)
6. Dergachev A., D. Armstrong, A. Smith, T. Drake, M. Dubois, "3.4-μm ZGP RISTRA nanosecond optical parametric oscillator ppumped by a 2.05-mm Ho:YLF MOPA system", Optics Express, 15, page 14404-14413, (2007)
7. Koen, W., C. Bollig, H. Strauss, M. Schellhorn, C. Jacobs, M.J.D. Esser, "Compact fibre-laser—pumpud Ho:YLF oscillator-amplifier system", Appl. Phys. B, 99, page 101-106, (2010)
8. Singh, U.N., Y. Bai, J. Yu, M. Petros, P. Petzar, B. Trieu, H. Lee, "High repetition rate pulsed 2-micron laser transmitter for coherent $CO_2$ DIAL measurement", Pro. 15th Coherent Laser Radar Conference, pages 77-80, (2010)

9. Edouart, D., F. Gibert, F.L. Mounier, D. Bruneau, P. Flamant, “2-micron high-repetition rate laser transmitter for biosphere-atmosphere flux measurements”, 25th ILRC, pages 31-34, (2010)
10. Shen, D.Y., W.A. Clarkson, L.J. Cooper, R.B. Williams, “Efficient single-axial-mode operation of a Ho:YAG ring laser pumped by a Tm-doped silica fiber laser”, Optics letters, 29, page 2396-2398, (2004)
11. Lippert, E., G. Rustad, G. Arisholm, K. Stenersen, “High power and efficient long wave IR $ZnGeP_2$ parametric oscillator”, Optics Express, 16, page 13878-13884, (2008)