

2-micron Laser Development for Wind and CO₂ Sensing

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1. Introduction

We are developing 2-micron eye-safe solid lasers doped with Tm and/or Ho, which are useful components to construct lidar instruments for remote sensing of wind, H₂O and CO₂ concentration¹. Tm,Ho:YLF laser oscillator of 100mJ output and Tm,Ho:YLF laser amp of 460mJ have been demonstrated^{2,3}. These lasers used a composite laser rod and 28 laser diodes. Applying those technology, we have developed a pulsed laser of moderate output of 50-100mJ at 30Hz for a CO₂ DIAL/Wind Doppler lidar system (Co2DiaWiL)⁴. The pumping module has 12 laser diodes and a Tm,Ho:YLF rod. We have tried to make a compact laser system (Trial Laser) for the future mobile lidar system development⁵. Using these experiences of the study of laser diode pumped and conductive-cooled Tm,Ho:YLF lasers, more compact mobile lidar system with the same type of pumping module is now in development⁶. It will be used for measurements of wind and CO₂ concentration. Recently, another possibility of high average power laser is shown. Ho doped laser end-pumped by Tm-fiber laser is a potential configuration for high average power output. Small energy difference between output 2-2.1-micron laser light and pumping 1.9-micron fiber laser light reduces the heat load to Ho doped laser rod. Outputs over 20mJ at 1kHz was obtained with MOPA configuration^{7,8} of Ho:YLF laser. High repetition lasers up to 10kHz for CO₂ measurement were reported^{9, 10}. We started to develop Tm-fiber laser pumped Ho:YLF laser with output of 20-50mJ at 200-300Hz to extend the observation range and get better accuracy.

2. Trial Laser

A compact laser was build up to test the stability of Tm,Ho:YLF laser. The pumping module is almost same as that for Co2DiaWiL. The laser should be operated in 50-80mJ output at 30-50Hz. The pumping module is set in a compact vacuum container (Figure 1). 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. Long pulse characteristics in a Fabry-Perot type resonator configuration are shown in Figure 2. It is similar to that obtained in the pumping module of Co2DiaWiL¹¹. Outputs were about 100mJ and 200mJ at LD current of 40A and 50A. The vacuum container with pumping module was set in the trial laser with a laser cavity similar to a ring laser of Co2DiaWiL but more compact one. The laser system was put under environment test for temperature change and longtime change of output. These results are used for the new mobile lidar systems⁵.

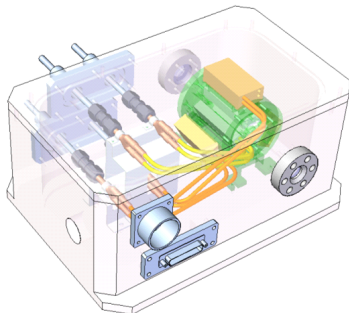


Figure 1. Pumping module in Vacuum container

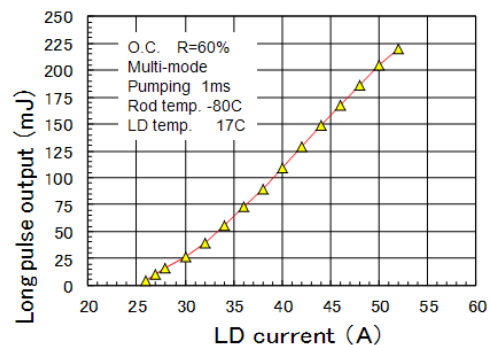


Figure 2. Long pulse output

3. Ho:YLF laser pumped by Tm-fiber laser

High power Tm-fiber lasers emitting 1.9-micron light are recently commercially available for end-pump Ho doped solid state laser. We started to develop a Ho:YLF laser, which emits at 2.05-2.06-micron and will be used for wind and CO₂ measurements. The pumping source is a random polarized Tm-

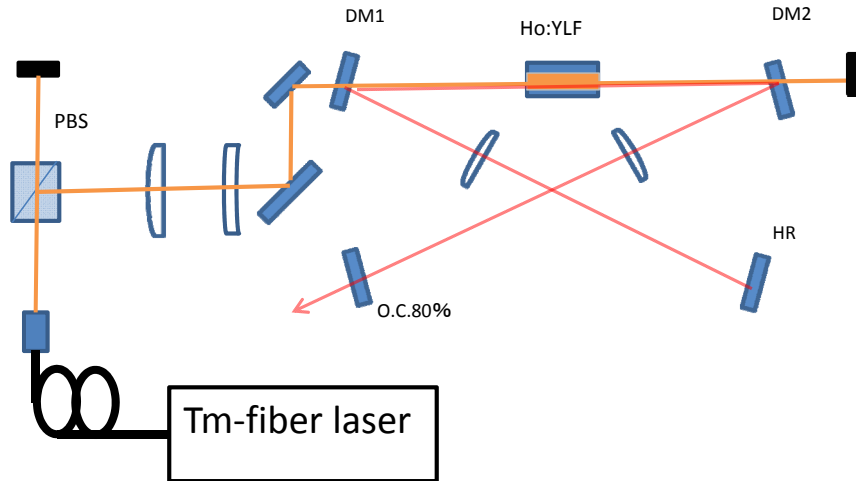


Figure 3. Layout of CW Fabry-Perot resonator

fiber laser (TLR-50 from IPG photonics). Its maximum output is 50W at 1940nm. We firstly set up a Fabry-Perot type resonator configuration. The layout of CW Ho:YLF Oscillator is shown in Figure 3. The laser rod is a Ho(0.5%):YLF crystal of 4mm diameter x 40mm length. The rod is conductive-cooled from three heat Cu sinks cooled by 15C water (Figure 4). The c-axis of the rod is set to vertical orientation and lasing takes place on the π -polarization. The 1940nm laser beam from Tm-fiber laser is separated to S- and P- polarized beams by a polarizing beam splitter. S-polarized beam is reduced by a telescope of two lenses. The reduced pumping beam passes through a dichroic mirror, DM1, to a pumping module in the resonator. The dichroic mirrors are coated for high transmission at pump wavelength and high reflection at laser wavelength. The rod is put in the c-axis vertically and the oscillator emits the laser light on the π -polarization. The cavity length is 1.5m. The CW output characteristics with an output coupler of the reflectance of 80% are shown at Figure 11. The threshold of the pump power is about 14W. Maximum output of about 6W is obtained at the pump power of about 22W. The pumping beam size becomes smaller according to the pumping power in this fiber laser. It is 1mm (intended size) at the position of the rod around pumping power of 20W.

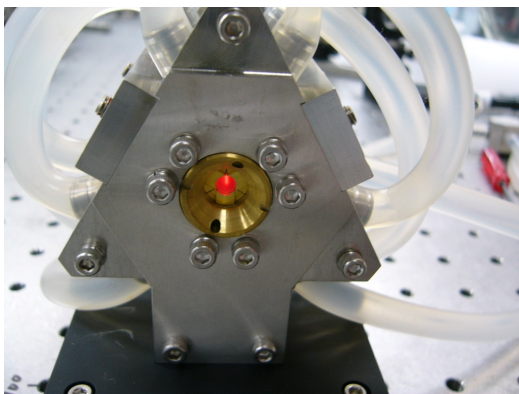


Figure 4. Pumping module of Ho:YLF laser

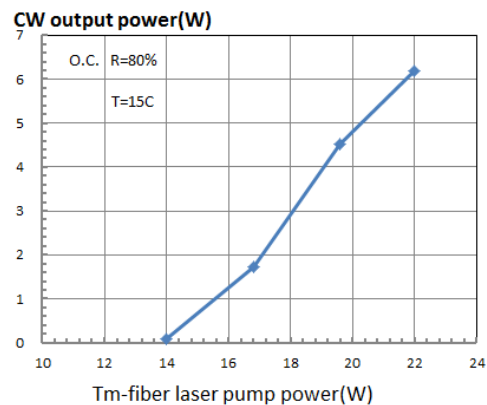


Figure 5. Output characteristics of F-P cavity

4. Ho:YLF Oscillator/Amplifier

Ring resonator configuration was set up after the Fabry-Perot configuration. The layout is shown in Figure 6. The cavity length of the oscillator is 3m. One direction emission was reflected by a HR mirror put after an output coupler of the reflectance of 70%. The temperature of cooling water is set to 17C. The decrease of the output in the temperature difference from 15C to 17C is about 5%. The maximum CW output of the oscillator was 5.6W at 22W pump power. An acousto-optic modulator is inserted for Q-switch mode operation. We tried it at 500Hz and obtained 3.8W output at 19.6W pump power. We will make more adjustment for Q-switch operation to obtain more energetic pulses.

We use master oscillator and power amplifier (MOPA) configuration. P-polarized pumping beam of the fiber laser is used for the amplifier with the same design of the pumping module. The polarization of the pumping beam is rotated by 90 degree using a half wave-plate to maximize absorption in the amplifier rod crystal which is also set for the c-axis to be vertical. The amplifier was operated in cw-regime. The output characteristics are shown in Figure 7. The abscissa indicates the sum of the oscillator pump power and amplifier pump power. In the 100% pump power of 47W, the amplifier output of 9.1W was obtained.

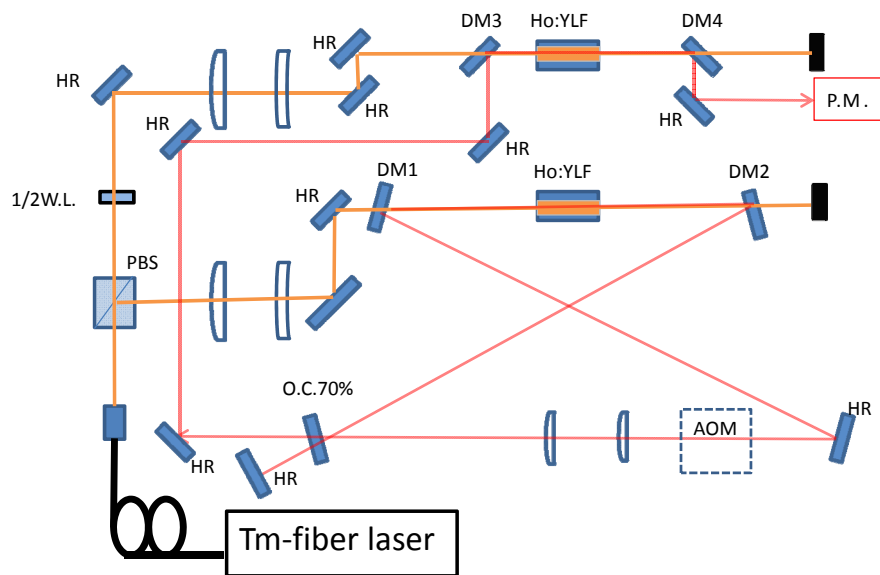


Figure 6. Layout of ring resonator and amplifier of Ho:YLF laser

Ho:YLF is attractive material to achieve high power Q-switch output. However, thinking of ground based observation of wind, we may use other laser crystals because the round-trip transparency even at off line wavelength (between CO₂ absorption lines) 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-

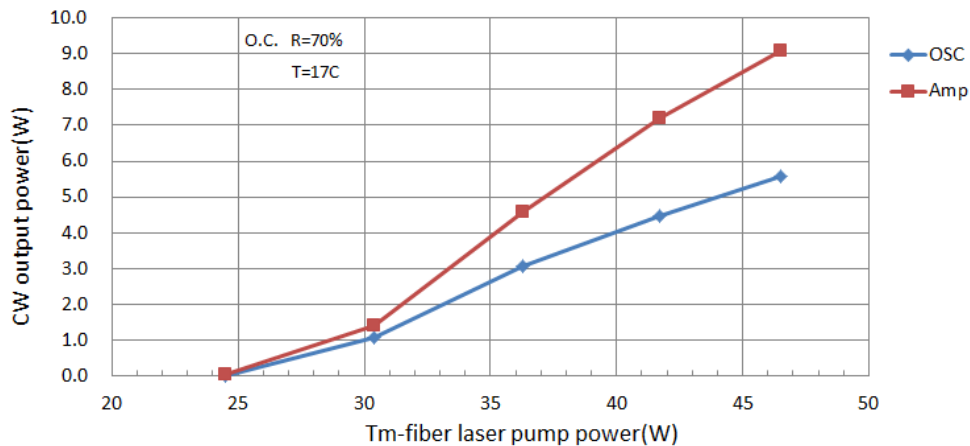


Figure 7 CW output characteristics of ring resonator and amplifier of Ho:YLF laser

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^{12, 13}.

5. Conclusion

We have developed a ground-based CO₂ 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 CO₂ concentration are usually made in 50-80mJ output at 30Hz. We constructed the trial laser. The pumping module showed the similar ability to that of the Co2DiaWiL. The trial laser was used for the test of the stability for developing new mobile lidar systems. Ho:YAG laser pumped by Tm-fiber laser is also studied. The laser will be used at relatively high repetition rate of 200-300Hz. The MOPA system showed a CW output of about 9W for the pumping energy of 47W. The developed lasers are conductive-cooled, eye-safe and solid-state. Then, these are suitable for space-borne lidars.

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