

HO:YLF LASER PUMPED BY TM:FIBER LASER

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ABSTRACT

A 2-micron Ho:YLF laser end-pumped by 1.94-micron Tm: fiber laser is described. A ring resonator of 3m length is adopted for the oscillator. The laser is a master oscillator and an amplifier system. It is operated at high repetition rate of 200-5000 Hz in room temperature. The laser outputs were about 9W in CW and more than 6W in Q-switched operation. This laser was developed to be used for wind and CO₂ measurements.

1. INTRODUCTION

2-micron solid lasers doped with Tm and/or Ho are suitable for remote sensing of wind, CO₂ and H₂O [1]. We have developed 100mJ pulse energy class laser diode(LD)-side pumped Tm,Ho:YLF oscillator and 460mJ pulse energy Tm,Ho:YLF amplifier [2,3]. The pumping module of these lasers used composite rod and 28 LD. It was heavy and high cost. We cooled the rod conductively to -80C in the vacuum container for effective laser output. For easy operation and accessibility, we developed moderate output compact lasers with a pumping module using non-composite rod and 12 LD. The pumping module was also cooled to -80C. The output pulse energy is 50-100mJ at 30Hz and it was used for a CO₂ DIAL/Wind Doppler lidar system (Co2DiaWiL) [4]. Another method to get high average output power is to use high power CW Tm: fiber lasers emitting around 1940nm as a pumping source. Efficient pumping of Ho:YLF rod by Tm: fiber laser is possible [5,6]. High pulse repetition 2.05-2.06 micron Ho:YLF laser end-pumped by Tm: fiber laser were developed for CO₂ and wind measurements at [7,8,9]. Advantages of 1.9-micron pumping are low thermal load and possibility of the use of room temperature rod. Commercial pumping sources are available. High repetition is an advantage for CO₂ coherent DIAL measurements. Then, we are developing such

Ho:YLF laser for coherent measurements of CO₂ and wind. We describe the status of the development of Ho:YLF laser end-pumped by Tm: fiber laser here.

2. EXPERIMENTAL SET UP

A random polarized Tm: fiber laser of 50W maximum output at 1940nm (IPG Photonics) is used to end-pump the laser rod of a Ho(0.5%):YLF crystal of 4mm diameter x 40mm length. The rod in the pumping module is conductive-cooled from three heat Cu sinks which are cooled by water (Figure 1).

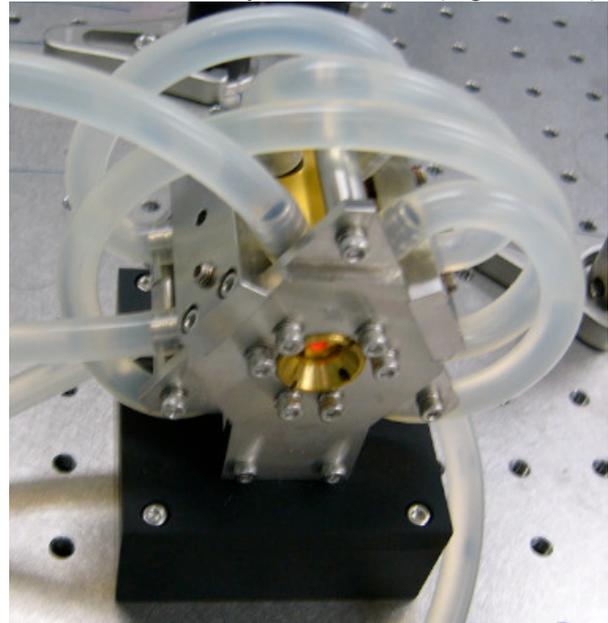


Figure 1 Pumping module of Ho:YLF

A long laser pulse width is needed to achieve narrow line width for coherent lidar applications. Adoption of long resonator is an easy way to get a long pulse. Ring resonator is also needed to avoid spatial hole burning. Then, we adopted a 3m ring resonator for the laser oscillator. The system configuration of the ring oscillator and also the amplifier is shown in Figure 2. S-polarized beam of the Tm: fiber laser is reduced to the size of about 1.2mm diameter by a telescope of two

lenses and enters to the resonator. The pump beam passes through a dichroic mirror (DM1) with high transmission for the pump light and high reflectivity for the laser light. After the pump beam is absorbed by the rod, the residual pump light passes through another dichroic mirror (DM2). P-polarized pump beam after a PBS is rotated by 90 degree by a half wave-plate. It is used to pump the amplifier rod in the pumping module of the same design. The pump beam for the amplifier is also reduced in size to match with the oscillator laser output by a telescope of two lenses and passes DM3. The laser output of the oscillator is connected to the amplifier. The unidirectional operation is achieved by a high reflection mirror put after the output coupler of 90%. An acousto-optic modulator is inserted for Q-switched operation. A dichroic mirror (DM3) reflected the oscillator laser light to the amplifier rod. The amplified laser light is reflected by a dichroic mirror (DM4), and the residual pump beam energy passes through DM4 and enters a dumper.

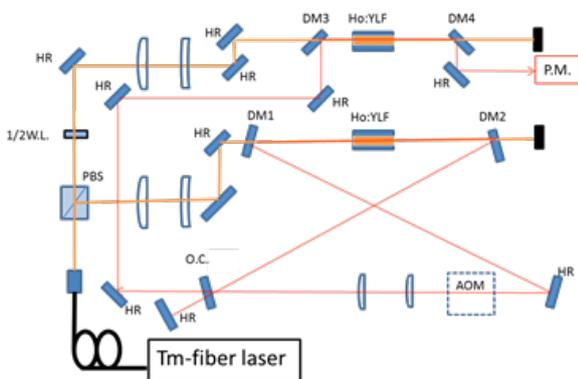


Figure 2 Oscillator and amplifier configuration

3. RESULTS

We show the CW output characteristics in the ring oscillator and also the amplifier in Figure 3. Lenses with focal length of 1000mm and 4000mm were used in the rig resonator. In the maximum input, the oscillator output was 5.6W and amplifier output was 9.1W. The gain by the amplifier is about 1.6. Figure 4 shows oscillator and amplifier output characteristics at CW and 5 kHz Q-switch operations. Lenses with focal length of 1000mm and 5000mm were used in the

ring resonator. The maximum output at 5 kHz was 7.5W, compared with 7.9W at CW.

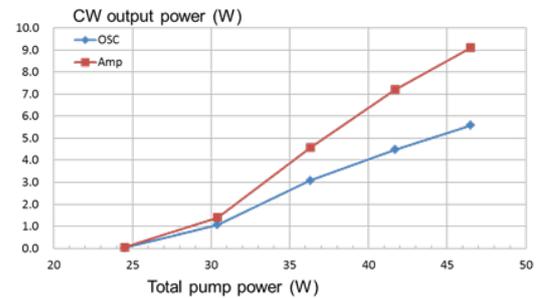


Figure 3 CW output characteristics with lenses of 1000mm and 4000mm focal lengths

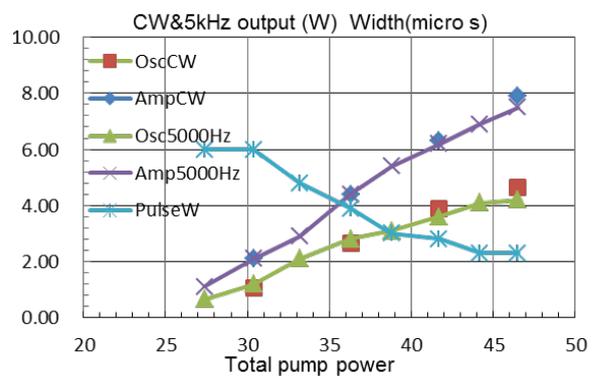


Figure 4 Oscillator and amplifier output characteristics at CW, and 5 kHz Q-SW operation with lenses of 1000mm and 5000mm focal lengths

Slope efficiency at 5 kHz pulse operation was about 33%. Pulse width was measured for the oscillator and decreased according to pump power. The minimum pulse width of 2.3 μ s at 5 kHz was obtained at the maximum total pump power of 46.5W. The amplifier output characteristics at 200 Hz to 5 kHz are shown in Figure 5. The output characteristics were similar in more than 1 kHz. According to the decrease of the repetition, output became smaller in 200 – 500 Hz.

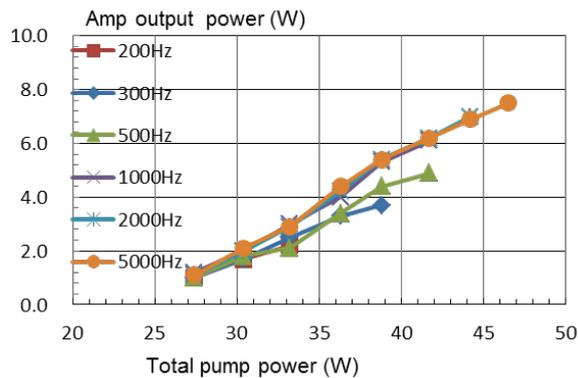


Figure 5. Amplifier output characteristics at 200 Hz to 5 kHz.

We did not make experiment in the pump condition where pulse energy seemed to be too large in view of damage concern. The maximum pulse energy of 12mJ in this experiment was obtained at the repetition of 300 Hz and the total pump power of 38.8W. The oscillator and amplifier pulse energy dependences on repetition rate between 500Hz and 5KHz are shown in Figure 6 for the total pump power of 41.7W. The pulse width is also shown in the Figure 6.

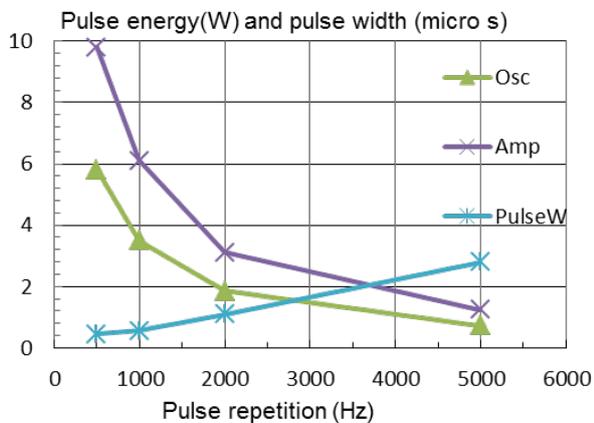


Figure 6. Oscillator and Amplifier output and width dependences on pulse repetition at 500 Hz to 5 kHz for a pump power of 41.7W.

According to the decrease of the repetition, the pulse energy became larger and the pulse width did shorter. The amplifier pulse energy at 500 Hz is 9.8mJ and the pulse width is about 0.44 μ s. According to increase of pulse energy, the pulse width became short. High peak power may damage some of optical components, especially dichroic mirror DM1 and DM2. We need more consideration about damage in the dichroic mirror to obtain higher pulse energy in the lower

repetition. Then we will use a lower reflectance output coupler than 90% for the oscillator.

We will use a ramp-and-fire mechanism [10] for injection-seeding. HR mirror will be removed and the CW seed source will be introduced to the resonator through the output coupler. In this case, unidirectional operation could be induced without the HR mirror after the output coupler.

4. CONCLUSIONS

We made an experiments of a Ho:YLF laser end-pumped by Tm: fiber laser. The ring oscillator and amplifier system was operated at CW and high repetition rate of 200-5000 Hz. The MOPA system showed maximum outputs of 8 - 9W at CW. The average output at repetition more than 1 kHz was similar to that at CW. Pulse outputs of more than 6W were obtained at more than 1 kHz. However efficiency was smaller at 200 - 500 Hz. The maximum pulse energy of about 12mJ was obtained at the repetition of 300 Hz and the total pump power of 38.8W. We could expected higher pulse energy in the repetition rate of 200 - 1000 Hz, if we used maximum pump power. The use of lower reflectance output coupler will permit higher pulse energy. More consideration about damage concern is important to achieve higher pulse energy. This laser will be used for wind and CO₂ concentration measurements. High repetition is especially suitable to CO₂ coherent DIAL observations.

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