Efficient operation of conductively cooled Ho:Tm:LuLiF laser oscillator/amplifier

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Abstract: A conductively-cooled Ho:Tm:LuLiF laser oscillator generates 1.6J normal mode pulses at 10Hz with optical to optical efficiency of 20%. When the laser head module is used as the amplifier, the double-pass small-signal amplification excesses 25.

1. Introduction

Tm:Ho:LuLiF laser has significant applications in the study of global warming because its operating wavelength is in eye-safe range and can be tuned to one of the CO_2 (a principal greenhouse gas) absorption lines. Ho:doped laser oscillator can generate high-energy pulses (>100mJ) and Ho:doped laser amplifier can amplify the pulses to joule-level energy. A master oscillator and power amplifier (MOPA) Tm:Ho:LuLiF system, where the 100mJ pulses from a Q-switched oscillator are amplified into >1J pulses by three power amplifiers, has been reported [1]. Such a system is not only able to measure the column content of CO_2 concentration, but also able to measure the distribution profile of CO_2 concentration in atmosphere.

To meet the requirement of air/space-borne lidar applications, the laser system has to be efficient and small. Fig.1 shows the energy level diagram of Ho:LuLiF crystal. The upper state and lower state of 2.053μm laser transition are the lower level of $^5I_7$ manifold and the upper level of $^5I_8$ manifold, respectively. According to Boltzmann's theory, the lower the temperature of Ho:LuLiF crystal, the lower the laser threshold. For example, the laser threshold corresponds to the population inversion is 22.6% at the temperature of 15°C, while that at the temperature of -25°C is 19.4%.
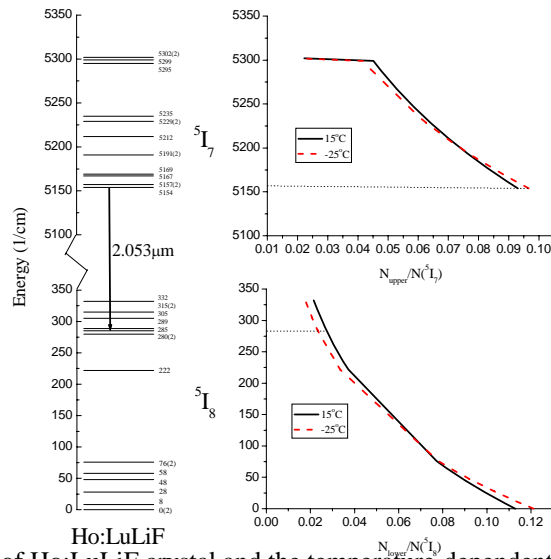

Fig.1. The level diagram of Ho:LuLiF crystal and the temperature-dependent population inversion.

In the conductively cooled Tm:Ho:LuLiF laser head, the crystal temperature can be cooled to the environmental temperature in the space. Another benefit for conductively cooled laser head is low pump

loss because the diode pump beams can directly reach the laser crystal without passing through the flow tube and flowing medium.

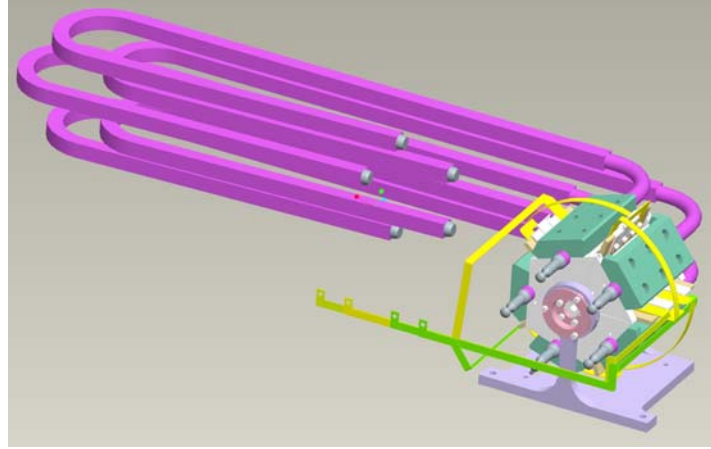## 2. Conductively-cooled laser head module

Fig.2 The conductively-cooled laser head module.

The conductively cooled laser head module is pumped from five sides with 20 diodes and the heat is removed by 5 heat pipes and, as shown in Fig.2. The heat pipes are connected to a liquid-cooled tank. The maximum pump energy for the laser head module can reach 8J. The laser crystal is pumped partially at π-polarization and partially at σ polarization. The maximum pumping absorption is at the wavelength of 779nm. The conductively cooled laser head module is sealed in a chamber where the nitrogen gas is filled.

3. Normal mode operation

The conductively cooled laser head module is used to build a linear cavity oscillator. The cavity length is 56 cm. One of the cavity mirrors is the concave mirror with a radius curvature of 1m. The other cavity mirror is the output copular with reflection of 40%. The output energy can reach 1.6J with slope efficiency of 30%. The optical to optical efficiency is 20%. When the pumping repetition rate is adjusted from 2Hz to 10 Hz, the output pulse energy doesn't significantly decrease until pumping pulse energy reaches 7J, as shown in Fig.3.
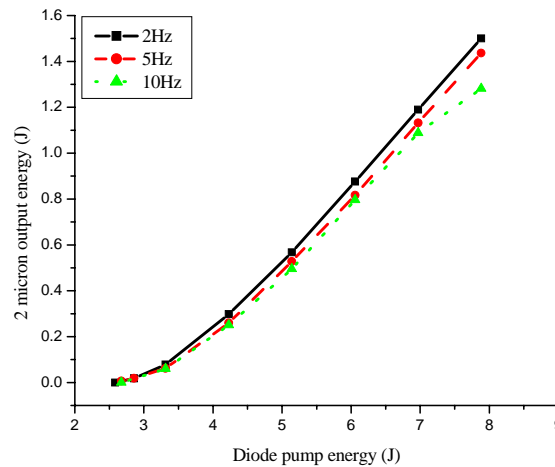

Fig.3. The normal mode output energy of linear-cavity oscillator via diode pumping energy.

4. Conductively cooled amplifier

The amplification performance of the conductively cooled laser head module is tested using 5Hz Q-switched probe pulses. The experimental setup is shown in Fig.4. The HeNe laser at the wavelength of 543.5nm is used to measure Ho: population inversion in the amplifier.
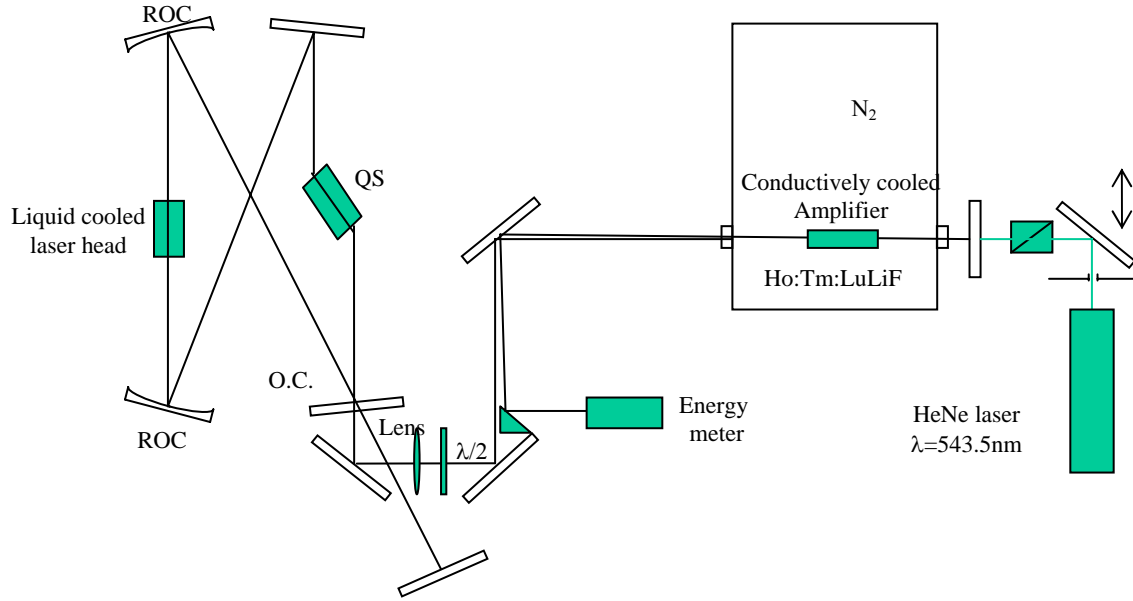

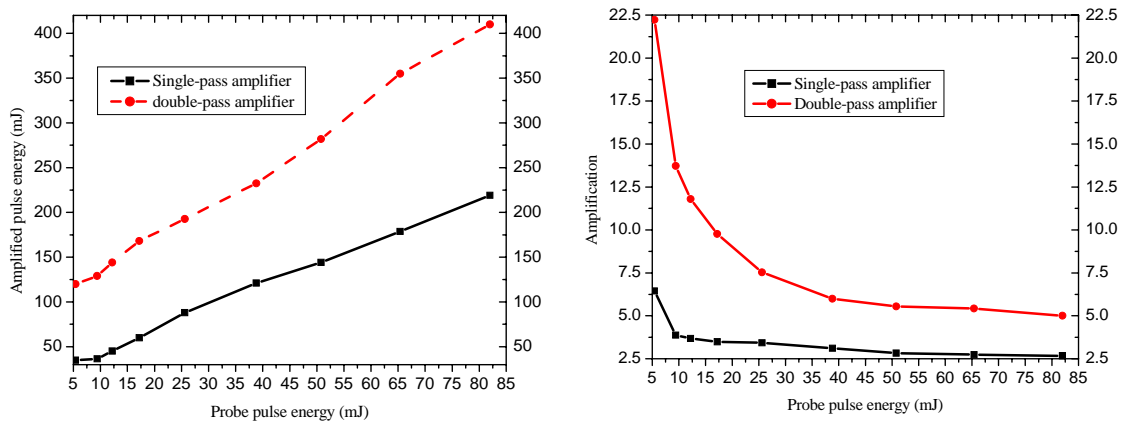Fig.4. The setup for studying the amplification performance of conductively cooled laser head module.

Fig.5. The single/double-pass amplified pulse energy and the amplification with different probe pulses.

The measured single/double pass amplified pulse energy as well as the corresponding amplification are shown in Fig.5. For a 5.4 mJ probe pulse, the double pass amplification is 22.5. The calculated double-pass small signal amplification excesses 25. For a 80mJ probe pulse, the double-pass amplified pulse energy is more than 400 mJ. All of these results are obtained when the pump pulse energy is at 5.6J. It proves that the gain of conductively cooled laser head module is two times higher than that reported in the previous literature.

References:
1. Jirong Yu, Bo C. Trieu, Ed A. Modlin, Upendra N. Singh, Micheal J. Kavaya, Songsheng Chen, Yingxin Bai, Paul J. Petzar, and Mulugeta Petros, "1 J/pulse Q-switched 2-μm solid-state laser", Opt. Lett. Vol.31 462-464 (2006)