An Efficient End-Pumped Ho:Tm:YLF Disk Amplifier

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Abstract: An efficient diode-pumped, room temperature Ho:Tm:YLF disk amplifier was realized by end-pump configuration. Compared to side pump configuration, about a factor three improvement in system efficiency has been demonstrated.
OCIS codes: (140.3280) Laser amplifiers; (140 3480) Lasers, diode-pumped

Introduction

Space based wind sensing coherent Doppler lidar requires an eye-safe, high energy, high efficiency and single frequency laser transmitter. Laser output energy ranging from 500 mJ to 2 J with an efficiency of 5% is required for an operational space coherent lidar[1]. We previously developed a high energy Ho:Tm:YLF master oscillator and side pumped power amplifier system[2] and demonstrated a 600-mJ single frequency pulse at a repetition rate of 10 Hz. The amplifier system consists of four side-pumped amplifiers, each having 7 J pump energy. Although the output energy is high, the optical-to-optical efficiency is only 2%. In particular, the optical-to-optical efficiency is about 1% for the first two amplifiers, due to the fact that they are not operated in the saturation region. In addition, it is difficult to apply conductive cooling technology to dissipate the heat from both the laser rod and laser diodes in a side-pump rod configuration. Designing a high energy, highly efficient, conductively cooled 2-µm laser remains a challenge. In this paper, we report a diode-pumped 2-µm amplifier with end-pump configuration. Compared to side pump configuration, about a factor three improvement in system efficiency has been demonstrated. The amplifier's efficiency is augmented by a higher pump density and a better mode overlap between the pump and the probe beam. This amplifier can be made very compact in size and can be conductively cooled for both the laser disk and pump diodes. This efficient disk amplifier is a promising candidate for use in an efficient space coherent lidar system.

Experimental set up

A 2-µm laser used in coherent wind lidar requires high energy as well as a well controlled output, that is single frequency, >200 ns pulse length, near diffraction limited beam. Thus, a 2-µm high energy laser usually consists of an oscillator and multiple amplifier stages. Efficient amplification of the 2-µm laser is important since the amplifier will consume most of the available electrical power. To date, most of the 2µm amplifiers have used a transverse or side-pumped laser rod configuration to pump the laser gain medium. In laser rod geometry, it is difficult to extract the energy stored near the lateral surfaces of the laser rod, which limits the efficiency of the system. In longitudinal or end-pumped configuration, on the other hand, only the center of the disk can be pumped which allows the beam to be amplified to access all of the pumped volume without suffering diffraction losses.

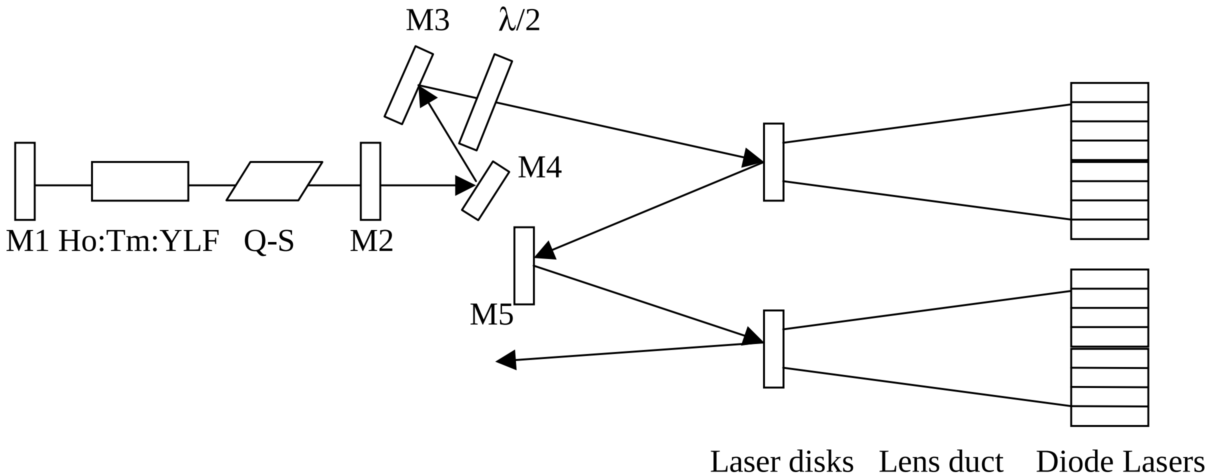

Figure 1. Optical layout of the end-pumped disk amplifier

Figure 1 shows an optical diagram for a two-stage end-pumped disk amplifier. In this configuration, the laser disks are longitudinally pumped by laser diodes through lens duct. Two laser diode arrays (LDA) are in each diode laser assembly. Each LDA has 13 laser-diode bars with a peak output power of 100 W per bar. A microcylindrical lens is attached near each surface of the laser bar to reduce the divergence of the LDA's fast-axis radiation, increasing the brightness of the radiation[3]. A nonimaging lens duct is used to couple the radiation from the laser diode arrays to the laser disk. The use of a lens duct can significantly increase the irradiance of LDA's on a laser disk[4]. The lens duct has the advantages of high coupling efficiency and simple structure, which are essential for the design of high power amplifiers with large laser diode arrays as the pump source. A ray trace model for the lens duct indicates that as high as 98% coupling efficiency could be achievable. However, the measured coupling efficiency of the lens duct is about 83%. The reason for the low coupling efficiency is that the microcylindrical lens may not be perfectly aligned with the emitting junctions of the laser diodes bar, resulting in poor transmission of the diode rays through the lens duct. The lens duct alignment is not sensitive to linear translation, but it is very sensitive to angular adjustment. A Si camera was used to monitor the image of pump beam exited from the lens duct to obtain prefect alignment of the lens duct with the pump diodes. The pump beam with octagonal shape emerges from the end surface of the lens duct and enters the input surface of a Ho:Tm:YLF disk. The pump beam has a beam waist of 1.65 mm and is located at 2 mm from the output surface of the lens duct. The laser disk is currently water-cooled to a temperature of 15°C, but can easily be changed to a conductively cooled system. The input surface of the laser disk is dichroic, with high reflectivity at 2 µm and high transmissivity at 792 nm. The exit surface of the laser disk is antireflection coated at 2 µm and high reflection coated at 792 nm, so the unabsorbed pump energy can be reflected back to pump the disk gain media again. The c-axis of the laser disk is parallel to the polarization of the diode laser to obtain maximum absorption.

Two turning mirrors, M3 and M4, direct the probe beam from the oscillator to the amplifier disk so that the probe beam can be easily scanned through the laser disk to find a maximum gain position. A half wave plate is inserted into the beam path to align the probe beam polarization with the c-axis of the Ho:Tm:YLF disk. The probe beam enters into the disk with a small angle. It is reflected by the other side of the laser disk and double passes the gain medium.

Result and Discussion

Ho:Tm:YLF crystal is an attractive choice for a 2-μm laser amplifier. It has a usable effective stimulated emission cross section and low thermal induced focusing. A comprehensive model has been developed to predict the performance of the Ho:Tm:YLF laser amplifier[5]. The amplifier performance depends on pump fluences as well as the product of the Ho, Tm doping concentration and the disk thickness. A variety of Ho and Tm doping concentrations have been selected; Ho varied from 0.007 to 0.015, and Tm varied from 0.06 to 0.08. The disk thickness varied from 3.0 mm to 6.0 mm. The probe beam energy in normal mode and Q-switch mode is varied from 20 mJ to 80 mJ to cover wide input range. Of all the disk samples, the laser disk doped with 6% Tm and 1% Ho with 4.0 mm or 5.0 mm thickness gives the best performance. This result concurs with a model simulation, which indicated that the optimum disk thickness for the doping concentration is between 4.0 and 5.0 mm.

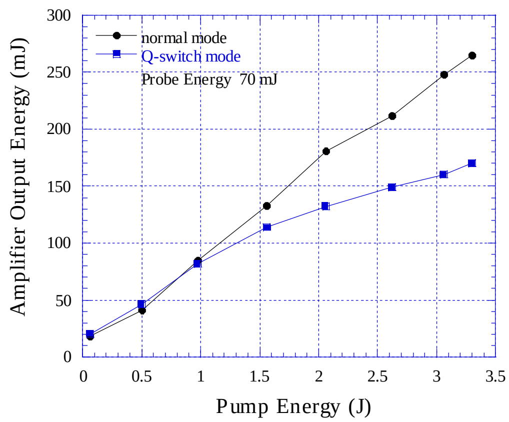

Fig. 2. End pumped disk amplifier performance for both Q-switch and normal mode operation.

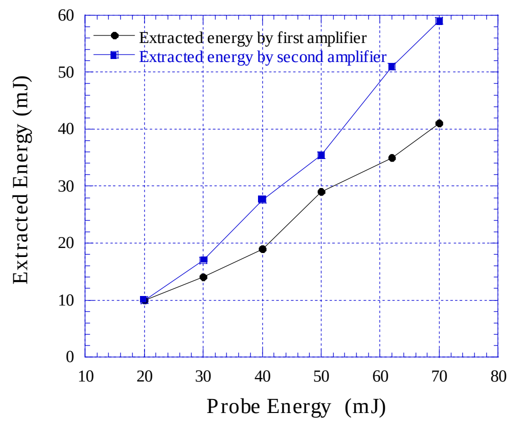

Fig. 3. Extracted energies from the first and second amplifier

Figures 2 shows the amplifier performance for both normal mode and Q-switch mode operation with a probe energy 70 mJ. The amplifier reaches optical transparency at a pump energy of ~ 700 mJ in both cases. As the pump energy increases, the probe beam energy is amplified. However, the amplifiers extract more energy in normal mode operation than in Q-switch operation. In Q-switch operation, the energy is extracted from the amplifier, which was stored in the Ho:Tm:YLF prior to the arrival of probe pulse. Although the amplifier gain may be higher; but it suffers from up-conversion loss at higher pump density. Thus, the normal mode operation usually gives a better gain. One hundred mJ of energy is extracted from the two-stage amplifier with pump energy of 3.3 J in Q-switch operation. The optical-to-optical efficiency of the amplifiers is 0.03. The total energy from the amplifiers reaches 170 mJ. At the same probe energy, the optical-to-optical efficiency is only about 0.01 for a side-pumped Ho:Tm:YLF amplifier[2]. Compared to side pump configuration, approximately a factor three improvement in system efficiency has been obtained.

Extracted energies from the first and second amplifier as a function of probe energy are plotted in Fig. 3. The second amplifier always extracts more energy than the first amplifier does. As the probe energy increases, the extracted energy for both amplifiers continue to increase approximately linearly indicates that saturation is not being approached. Consequently, more efficient amplifier performance is expected with higher probe energies or double pass technologies. To obtain higher 2-μm laser energy, a third and fourth amplifier can be incorporated into the system. Then, the system efficiency would be further improved as a high energy amplifier system.

Conclusion

An end-pumped Ho:Tm:YLF disk amplifier operating at room temperature has been demonstrated. A significant improvement in optical-to-optical efficiency has been obtained. Compared to a side pumped Ho:Tm:YLF amplifier[2], the end-pumped disk amplifier provides similar gain with much higher efficiency. The efficiency of this system can be further augmented by adjusting the alignment of the lens duct with the pump diodes and by optimizing the doping concentration and thickness of the laser disk. The configuration of the end-pumped disk amplifier is quite simple and it can easily be conductively cooled. It is also relatively easy to scale the energy by putting several amplifiers in series. This highly efficient disk amplifier is a promising candidate for use in an efficient space lidar system.

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