Efficient Tm:Fiber Pumped Solid-State Ho:YLF 2-µm Laser for Remote Sensing Applications

Upendra N. Singh[1], Yingxin Bai[2], Jirong Yu[1], and Mulugeta Petros[1]
[1]*NASA Langley Research Center, Hampton, VA 2368, USA*
[2]*Science Systems and Applications, Inc, One Enterprise Parkway, Hampton, VA 2366, USA*
Upendra.N.Singh@nasa.gov

Abstract: An efficient 19 W, TEM_{00} mode, Ho:YLF laser pumped by continuous wave Tm:fiber laser has been demonstrated at the room temperature. The slope efficiency and optical-to-optical efficiency are 65% and 55%, respectively.
OCIS codes: (140.3580) Lasers, solid-state; (140.3510) Lasers, fiber.

1. Introduction

Ho lasers operating around the wavelength of 2 μm have many specific applications in atmospheric surveillance (such as wind/CO_2 measurement) due to high water absorption, strong aerosol scattering and eye-safety [1]. Diode pumped Ho:Tm co-doped laser crystal is the most common way to generate high energy 2 μm laser [2], but upper laser state absorption, Tm and Ho energy sharing, concentration quenching, as well as large heat loading limits the efficiency. One way to eliminate or alleviate these effects is to make Ho and Tm in separate crystals. Experimentally, higher efficiency has been obtained from a diode pumped Tm:YAG laser pumped Ho:YLF laser [3]. In recent years, great advancement have been made in fiber laser technology, and Tm:fiber lasers with an output of > 100W are commercially available. Compared to a Tm:solid-state laser, the Tm:fiber laser has a higher efficiency (long interaction length and energy trap in the waveguide) and easier heat removal (long length and small diameter). A higher wall-plug efficiency was demonstrated when a Tm:fiber laser replaces the Tm:solid-state laser as the pump source for Ho:YLF laser [4,5].

In this paper, we report a Tm:fiber laser pumped Ho:YLF laser with highly efficient continuous-wave operation at room temperature. The slope and optical-to-optical efficiencies are 65% and 55%, respectively.

2. Laser configuration

The designed Tm:fiber laser pumped Ho:YLF laser has a zigzag configuration and is as shown in Figure 1. The maximum output power of the Tm:fiber pump laser is 40W in random polarization. The radius of its output beam is about 5mm and the peak wavelength is 1.941μm. It is off the absorption peak of Ho:YLF crystal by 2 nm, but there is still strong absorption at the wavelength. This pump beam is focused on the Ho:YLF crystal by a concave mirror with one meter radius of curvature. The waist of the focused beam is 0.46mm at $1/e^2$. The full divergence angle of the focused beam is about 2.6 mrad. For mode matching, the pump and laser beams have the same confocal parameters. Ho:YLF lasers present low threshold and high efficiency when the pump polarization is at π orientation due to the birefringent nature of the crystal. By appropriate feedback from the back mirror of the laser, the polarization of Tm:fiber laser output is changed from random polarization to linear polarization. This modification creates >90% pump power (34.4W) injected to laser crystal at π-polarization. The Ho:YLF crystal is 1% Ho doped concentration and 5mmx5mmx30mm in dimension. It is cooled by refrigerated water at 10^oC. The laser cavity consists of two flat highly reflected mirrors, one concave (the radius of curvature is 0.5m) and one flat coupler (R=40%). The total laser cavity length is 1.3m.

3. Laser performance

Based on quasi-three level modeling, pump absorption and saturation depend on laser intensity. On the other hand, laser amplification and saturation depend on pump intensity in the crystal. Small pump volume is desirable for obtaining high efficiency, but possible crystal damage must be considered for the reduced pump beam. In our experiment, the pump beam size on the front of Ho:YLF crystal is 0.512mm in radius. The experimental result is depicted in Fig.2. The laser slope efficiency is 64.72% with a threshold of 5.36 W. The maximum output power is 19W in TEM_{00} mode at 2.051μm when the π-polarization pump power is 34.4 W. The corresponding optical-to-optical efficiency is 55.23%.

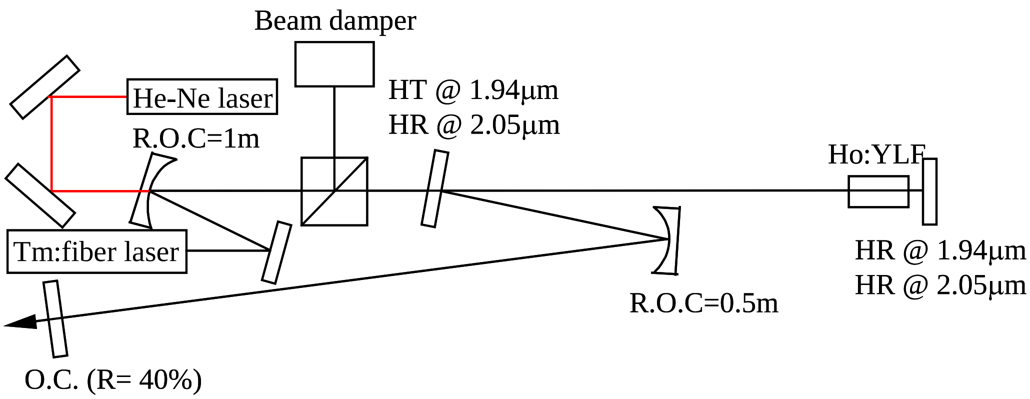

Fig.1. Tm:fiber laser pumped Ho:YLF laser.

The operating wavelength of Ho:YLF laser can be switched between 2.064 μm or 2.051μm. The formula to describe the small signal gain of Ho:YLF crystal and critical pump power intensity in the crystal has been derived theoretically. When the average pump power density in the Ho:YLF crystal is higher than the critical value, the small signal gain at the wavelength of 2.051μm is higher than that of 2.064μm; otherwise, the small signal gain at the wavelength of 2.064μm is higher. Therefore, the selection between the operating wavelengths, 2.064 μm or 2.051μm, can be implemented by adjusting the pump power intensity. Also, this wavelength switching can be realized by changing the output coupler. The change of output coupler will result in changing intracavity laser intensity. This, in turn, will change the pump absorption of Ho:YLF crystal because pump absorption is a function of laser intensity, and will indirectly change the average pump intensity in the laser crystal.

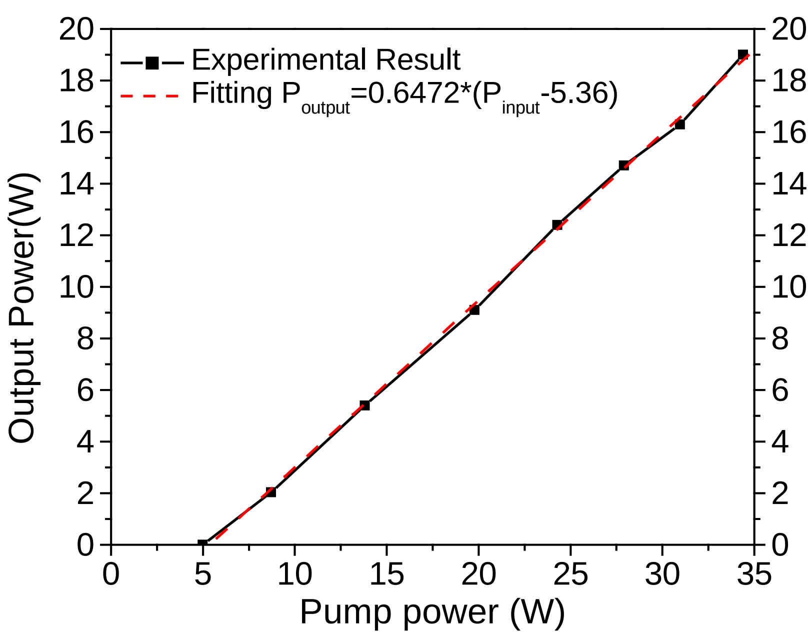

Fig.2. Laser output power versus pump power

4. Summary

We have designed a Tm:fiber laser end-pumped Ho:YLF laser considering thermal lens effect in the Ho:YLF crystal. This design has the following characteristics: mode matching between pump and laser beams, small pump volume, and controlling pump beam from random polarization to linear polarization by supplying linear polarization feedback to the Tm:fiber laser. The continuous-wave TEM_{00} mode laser power at 2.05 μm can reach 19 W at room temperature. The corresponding slope efficiency and the optical to optical efficiency are 65% and 55%, respectively.

5. References

[1] Mulugeta Petros, Jirong Yu, Tony Melak, Bo Trieu, Songsheng Chen, Upendra N. Singh, and Yingxin Bai, *"High energy totally conductive cooled, diode pumped, 2*μm *laser"*, in ASSP 2005 OSA Topical Meeting, MB11.

[2] Jirong Yu, Alain Braud and Mulugeta Petros, *"600-mj, double-pulse 2-μm laser"*, Opt. Lett. Vol.28 540-542 (2003)

[3] Alex Dergachev, Peter F. Moulton, and T. E. Drake, *"High-power, High-Energy Diode Pumped Tm:YLF–Ho:YLF–ZGP laser system"*, OSA TOPS Vol.83, John J. Zayhowski ed. 137-141,2003

[4] A. Dergachev, P.F. Moulton, and T. E. Drake, *"High-power, high-energy Ho:YLF laser pumped with Tm:Fiber laser"*, in ASSP 2005 OSA Topical Meeting, PDP 405.

[5] D. Y. Shen, W. A. Clarkson, L. J. Cooper, and R. B. Williams, *"Efficient single-axial-mode operation of a Ho:YAG ring laser pumped by a Tm-doped silica fiber laser"* Opt. Lett. Vol.29, 2396-2398(2004).

.