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Efficient Ho:YLF Laser Pumped by a Tm:fiber Laser

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Abstract: A thulium fiber laser pumped Ho:YLF laser delivering 45.1 W in a near diffraction-limited beam when pumped with 84.7 W is demonstrated. The optical-to-optical efficiency of 53 % compares favorably with similar Ho:YAG lasers.
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1. Introduction

Laser sources emitting in the 2 micron region is of particular interest for applications in medicine and remote sensing. In addition, they are also desirable pump sources for efficient optical parametric oscillators operating in the 3-5 µm band as both the signal and the idler generated from 2 micron pump light can fall within the band [1]. This is not the case with 1 micron pump sources. Additionally; while solid-state laser sources in the 1 micron region (Neodymium based lasers) are well established, sources in the 2 micron region are still maturing.

Ho:YAG based solid-state lasers pumped with Thulium-doped fiber lasers has been a popular approach for several years to generate coherent light at 2 micron, delivering high average powers and good optical-to-optical efficiencies [1, 2], while Ho:YLF was used for low pulse repetition frequency Q-switched applications due to its long upper state lifetime [3-5]. Ho:YLF had more limited use in high average power applications as the low thermal fracture limit of YLF could pose a problem when pumping at the high intensity levels required for efficient cw operation. However, in addition to weaker thermal lensing, Ho:YLF does not suffer from thermally induced birefringence which must be mitigated through various techniques when using Ho:YAG crystals in high-powered lasers. If thermal damage of Ho:YLF crystals is avoided, high-power laser configurations can be implemented without the need of end-capped crystals to reduce thermal lensing effects and stresses from end-bulging [2], as well as polarization optics that would otherwise be needed to reduce the effect of thermally induced birefringence exhibited by Ho:YAG [1].

In this paper we present a Tm-doped fiber laser pumped Ho:YLF laser operated in both continuous and Q-switched modes. The laser delivered an average power in excess of 45 W with an optical-to-optical efficiency of 53 % in a near diffraction-limited beam, demonstrating that Ho:YLF based lasers can deliver high average powers and optical-to-optical efficiencies.

2. Experimental Setup

A schematic of the layout is shown in Figure 1. As pump source, a commercial Tm-doped fiber laser (Model TLR-80-1940, from IPG Photonics) is used, delivering up to 84.7 W of power in a single mode fiber at 1940 nm.

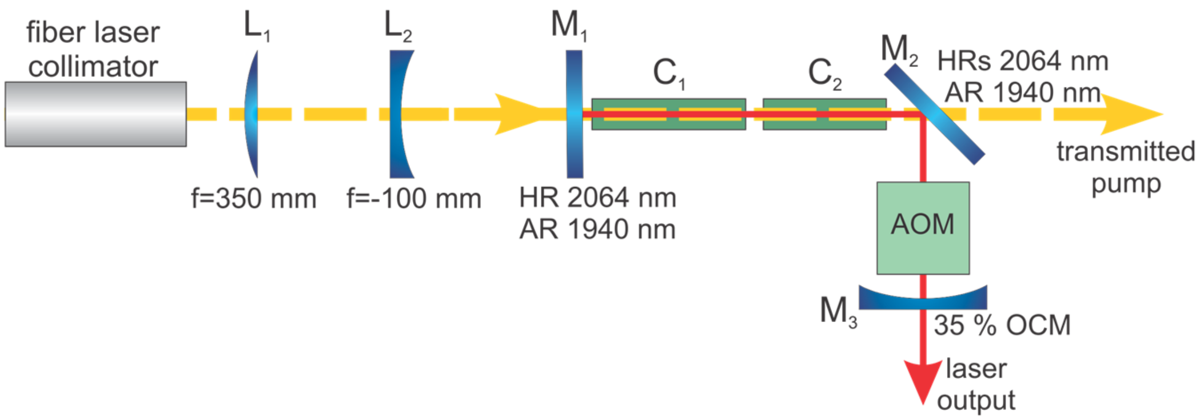

Figure 1: Experimental set-up of the Ho:YLF laser. A Tm-fiber laser pumps two collinear crystals.

The pump wavelength corresponds to an absorption peak of Ho:YLF. The pump light was focused into two collinear Ho:YLF rods using a reverse telescope consisting of a plano-convex lens L_1 (f = 350 mm) and a plano-concave lens L_2 (f = -100 mm). The average beam radius of the pump beam in the crystals was measured to be approximately 310 µm, almost half the size previously used in [6].

Two 0.5 % doped Ho:YLF rods were used in the cavity. The relatively low doping alleviated upconversion, but resulted in longer a gain medium being needed for sufficient absorption of the pump light. Consequently two crystals were used with lengths of 50 mm (C_1) and 40 mm (C_2). Both were mounted in water-cooled copper mounts, with a set temperature of 20 °C.

The cavity consisted of an input coupler mirror (M_1), a folding mirror (M_2) and an output coupler mirror (M_3). M_1 had high-transmission coatings for the 1940 nm pump light while being highly reflective at the laser wavelength of 2064 nm. The flat 45° folding mirror (M_2) was coated to be highly reflective at 2064 nm for the s-polarization while being highly-transmissive for the pump light (1940 nm). The laser therefore had a single-pass pump configuration. The polarization dependent reflective coating of the folding mirror also forced the laser to operate vertically polarized. As output coupler mirror (M_3), a concave mirror with a radius of 200 mm and a 65 % reflectivity at 2064 nm was used. By moving M_3, the cavity length (and mode size) could be varied. Various output coupler curvatures were evaluated to determine the optimal radius of 200 mm and final cavity length of 190 mm. For pulsing, a *Gooch & Housego* AOM (Model I-QS041-1.4C10V5) was inserted between M_2 and M_3.

Since the Ho:YLF crystals are birefringent (c-axis cut perpendicular to optical axis), each crystal had to be rotated to the desired angle. First C_1 was inserted with its c-axis vertical. The polarization dependent folding mirror M_2 would then force the laser to lase on the π-polarization. The second crystal (C_2) was inserted behind C_1 and rotated for maximum laser output. As the maximum laser output also coincided with the least amount of transmitted pump light, it can be surmised that the second crystal's c-axis was horizontal, as the first crystal's absorption would have partially polarized the pump light of C_2 due to the polarization-dependent absorption at 1940 nm in Ho:YLF. We have previously reported on a Ho:YLF MOPA system which exploited the partially polarized pump light transmitted through a laser crystal to pump an amplifier crystal by having their respective c-axis rotated with 90 ° with respect to each other [6]. This allowed efficient use of the unpolarized pump light without the need of polarizers, as used in [3]. This is the first time, however, that we have implemented this concept in a single cavity, with the first crystal lasing on the π-polarization while the second shorter crystal provides gain on the σ-polarization.

4. Results

The laser alignment and cavity length was optimized for maximum output power which coincided with good beam quality. The resulting power curve is shown in Figure 2. Laser threshold was at 14.6 W of incident pump power, with a maximum power output of 45.1 W when being pumped with 84.7 W. Depending on the inclusion or omission of the laser threshold data points, the slope was between 66 and 69 % (vs. incident). These measurements do not take the losses caused by the telescope (L_1 and L_2) and input coupler mirror (M_1) into account. At full pump power, the transmitted pump light was measured to be 7 W behind M_2, indicating pump absorption of nearly 83 %. Figure 3 (left) shows the laser beam intensity profile as recorded by a *Pyrocam III*. The laser's M^2 was measured to be better than 1.06 at full pump power. The laser wavelength was measured to be 2063 ± 3 nm using a *Jarrell Ash* monochromator. Pulsing at a repetition frequency of 50 kHz, laser pulse durations between 46.2 and 49.2 ns long were measured when using a PEM detector.

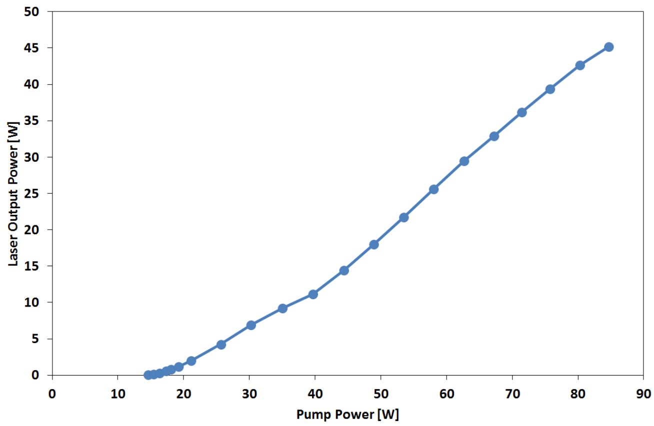

Figure 2: Laser output power (cw) as a function of incident pump power.

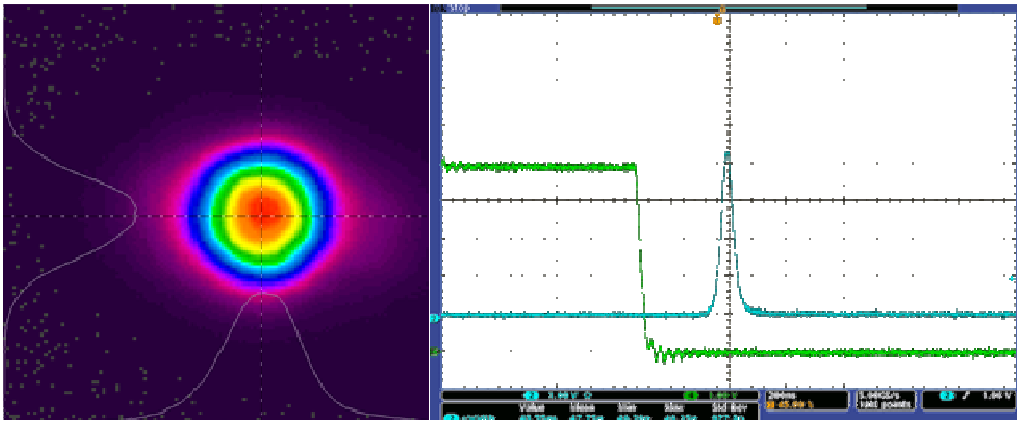

Figure 3: (left) Laser beam profile at full power and (right) pulse trace of laser when being Q-switched at a 50 kHz pulse repetition frequency.

5. Conclusions

We have demonstrated a thulium fiber laser pumped Ho:YLF laser which delivered a maximum of 45.1 W in a near diffraction-limited beam when pumped with 84.7 W. The optical-to-optical efficiency of 53 %, compares favorably with similar Ho:YAG lasers reported upon in [1] and [2] which had efficiencies of 51.3 - 60 % and 65 % respectively. This efficiency is achieved by pumping with a small diameter beam and good absorption of the pump light through the use of two laser crystals whose c-axes are orientated with respect to each other for optimal pump absorption.

6. References

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