EXPERIMENTAL ANALYSIS OF THERMAL EFFECTS IN HIGH-POWER DIODE-PUMPED TM,HO:YLF

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Introduction

Solid-state lasers with a wavelength of 2 μm have received increasing attention due to the use in a variety of fields such as medical and remote sensing applications.

The Tm,Ho:YLF is useful for high-energy applications. The Ho $^5I_7 \rightarrow {}^5I_8$ transition has a large cross section and a long life time, and the Tm absorption peaks at 784 and 792 nm can be pumped by diode lasers.

The Tm,Ho:YLF laser is a quasi-three-level system (Fig. 1). The Tm ions are excited to the $^3H_4$ level by absorption of the pump light. A cross-relaxation process between adjacent Tm ions (from $^3H_4$ and $^3H_6$ levels) produces two excited ions in level $^3F_4$. This process is dependent on the concentration of the Tm ions and works well for Tm doping above 2 %. These two excited ions transfer the excitation to two $^5I_7$ Ho ions [1,2].

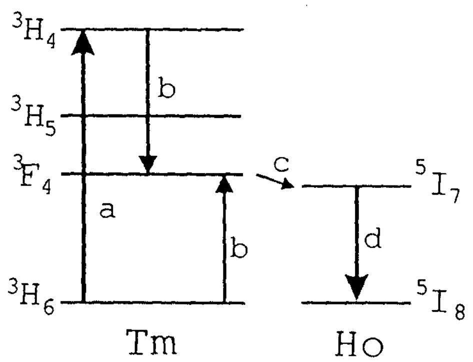

Fig. 1: Energy level scheme of Tm and Ho in YLF. (a) pump absorption (792μm), (b) Tm-Tm cross-relaxation, (c) Tm-Ho non-radiated energy transfer (d) laser transition (2,06μm)

This laser has a non-negligible thermal population of the lower laser level resulting in considerable reabsorption losses at room temperature [3,4]. Moreover, the system has upconversion processes in Tm and Ho ions, which reduces the population of the upper laser level [5]. The upconversion losses increase the threshold pump power and the reabsorption losses lower the laser slope efficiency. These effects can be decreased by cooling the crystal below –40 °C and employing a pump distribution that spreads the absorption uniformly over the whole crystal length by pumping it from both sides. Another alternative is to use quasi cw pumping of the crystal, allowing operation at temperatures above 0 °C.

This work demonstrates that the main loss mechanism of this crystal at ambient temperature is due to reabsorption only.

Experimental Setup

The laser was end pumped by a fiber lensed 20 W diode bar emitting at 792 nm. The beam, with emitting dimensions of $w_x = 1$ cm parallel to the bar and $w_y = 0.2$ mm perpendicular to the bar, was reconfigured into three columns of eight beams each using a two mirror beam shaper [6]. At the focus where the crystal is placed, the beam had dimensions of $w_x = 200$ μm and $w_y = 190$ μm, and quality factor of $M_x^2 = 130$ and $M_y^2 = 85$.

A laser resonator scheme is show in Fig. 2. It consisted of a flat, high reflector at the laser wavelength and high transmission (90%) at the pump wavelength, and a curved output coupler coated for low transmission (9%) at the laser wavelength. The cavity was held at 3 cm to minimize water vapor absorption.

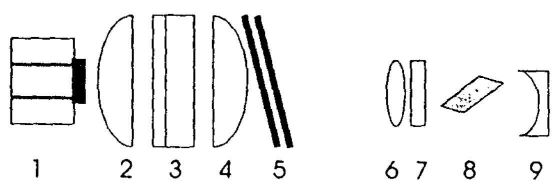

Fig. 2: Setup of the Tm,Ho:YLF laser. (1) diode and micro-lens, (2) f_x=2.5cm, (3) f_y=2.5cm, (4) f_x=2.5cm, (5) beam shaper, (6) f_{xy}=2.5cm, (7) plane mirror, (8) crystal, (9) output coupler R=10cm and T=9%.

The output coupler radius of curvature of 10 cm generates a beam waist of $w_x = 240$ μm and $w_y = 170$ μm inside the crystal for the infrared wavelength which is close to the pump beam dimensions at the focus. The total peak pump power incident on the crystal was 14 W due to losses in the beam shaper, lenses and the back mirror of the resonator.

The output power was measured by a Newport high-power detector (model 818T-150) with an accuracy of 3% . The crystal was placed on a copper heatsink whose temperature was controlled by a Neslab chiller.

Experimental Results

Keeping the crystal heatsink at a fixed temperature and varying the laser duty cycle, we observed a roll-over of the output power curve (Fig. 3). As the crystal temperature is decreased, the maximum output power occurs for larger duty cycles, indicating a dependence with crystal temperature.

We, therefore, studied the temperature dependence of the laser power by keeping the duty cycle in 20% and varying the crystal heatsink temperature (Fig. 4). By lowering this temperature from 20 °C to 6 °C, the output power increased 63%.

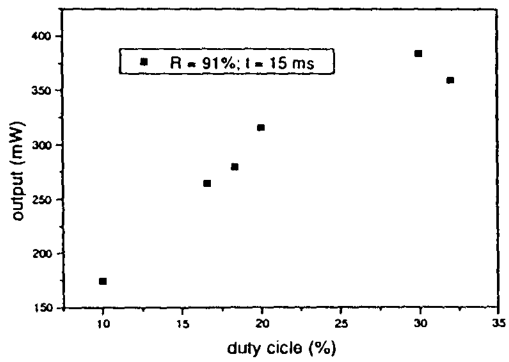

Fig. 3: Output power as a function of duty cycle at 6 °C for a 5.5 mm length Tm(6%),Ho(0,4%):YLF crystal.

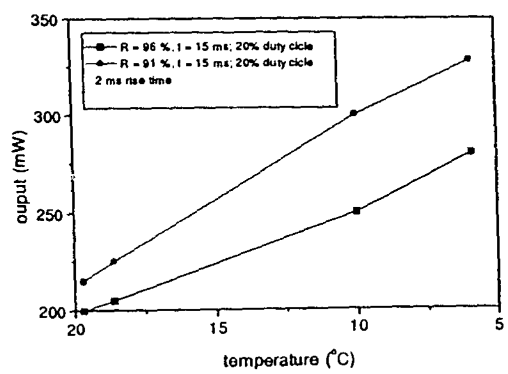

Fig. 4: Output power as a function of crystal temperature. The crystal had 5.5 mm length and 0.4% Ho concentration.

Detuning the diode emission wavelength from the Tm absorption peak was necessary in order to increase the laser efficiency. Figures 5 and 6 show the laser output for 0.4 and 1% Ho concentration crystals as a function of the diode temperature.

As seen in figure 6, more detuning is necessary in a crystal with higher Ho concentration. Comparing the output power for the two different Ho concentrations crystal we observed a lower efficiency for higher Ho concentration.

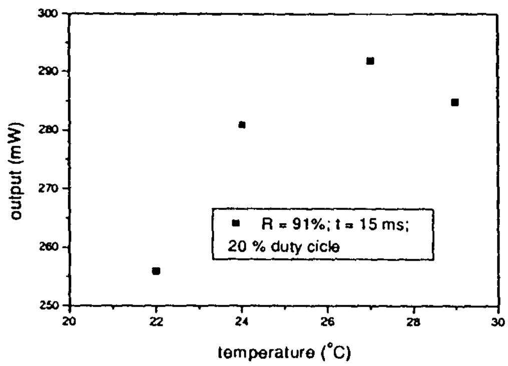

Fig. 5: Output power as a function of diode temperature for the Tm(6%),Ho(0,4%):YLF crystal. Maximum efficiency is achieved for a detuning of 2.1 nm.

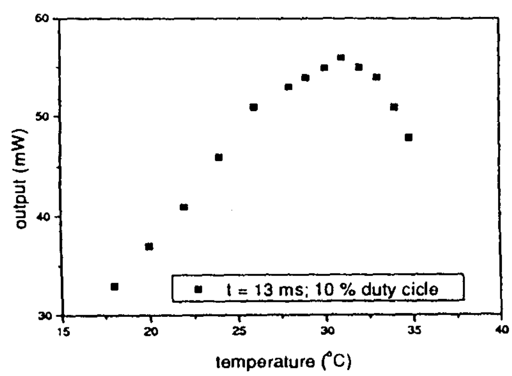

Fig. 6: Output power as a function of diode temperature for the Tm(6%),Ho(1%):YLF crystal. Maximum efficiency is achieved for a detuning of 3.6 nm.

Conclusion

We designed a series of experiments which demonstrate clearly that the main loss mechanism of this crystal at ambient temperature is due to reabsorption.

Specifically, the inclusion of an experiment whose only variable is the Ho concentration eliminates further doubts, that nonlinear losses have significant effects on laser efficiency.

At higher duty cycle, the increase in local crystal temperature of the pump volume causes a larger ground state population, which is the same as a higher Ho concentration. In both cases, detuning the diode emission wavelength from the Tm absorption peak, resulted in higher laser efficiency.

By lowering the crystal temperature, the laser increases its efficiency until a maximum of 28 % duty cycle, without the need for tuning the diode emission wavelength.

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