High Power Diode Pumped 2 µm Laser Operation of $Tm:Lu_2O_3$

P. Koopmann[1,2], S. Lamrini[2], K. Scholle[2], P. Fuhrberg[2], K. Petermann[1], and G. Huber[1]
1) Institute of Laser-Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany
2) LISA laser products, Max-Planck-Str. 1, 37191 Katlenburg-Lindau, Germany
philipp.koopmann@physnet.uni-hamburg.de

Abstract: We report the first diode pumped laser operation of thulium-doped lutetia in the 2 µm wavelength range. Output powers of more than 40 W and slope efficiencies of up to 42 % with respect to the incident pump power were achieved at room temperature.

OCIS codes: (140.3580) Lasers, solid-state; (140.2480) Lasers, diode-pumped; (140.3070) Infrared and far-infrared lasers

1. Introduction

There is an increasing interest in 2 µm laser sources due to a wide field of applications of these systems. They are used e.g. in gas detection, remote sensing, and medicine. Thulium-doped crystals provide great properties for these systems. Depending on the host, the laser wavelength lies between 1.8 and 2.1 µm whereas they can be pumped at around 800 nm, where high performance laser diodes are commercially available. Due to a cross relaxation process a quantum efficiency of up to two can be achieved [1].

Especially for high power systems, the thermal conductivity of the laser crystal becomes one of the limiting factors. For $Tm:Lu_2O_3$ a high thermal conductivity has been shown even for high dopant concentrations [2]. For this presentation a 1 at.% doped $Tm:Lu_2O_3$ crystal was grown by the heat exchanger method. With this crystal, the first diode-pumped $Tm:Lu_2O_3$ laser with output powers above 40 W and slope efficiencies of up to 42 % was built up. The output power was limited by the available pump power only, no initial thermal rollover could be observed.

2. Thermal Conductivity

In general, sesquioxides show a very high thermal conductivity compared to other standard host materials [3]. In addition, the thermal conductivity of many host crystals strongly decreases when they are doped with thulium because of the difference of the masses of the thulium-ion and the lattice-cation. The higher this difference is, the stronger the phonon propagation through the crystal gets constrained and the more the thermal conductivity decreases [4]. Since the masses of the thulium and the lutetium ion differ by only about 3 %, only a slight decrease of the thermal conductivity was measured for increasing Tm^{3+}-concentrations in lutetia (see Fig. 1 a). Increasing the dopant concentration from 0 to 5 at.% lead to a decrease of the thermal conductivity of 11 %. For comparison, the thermal conductivity of thulium-doped YAG has also been measured. A decrease from 10 $Wm^{-1}K^{-1}$ to 5.7 $Wm^{-1}K^{-1}$ can be observed when comparing dopant concentrations between 0 and 10 at.%.

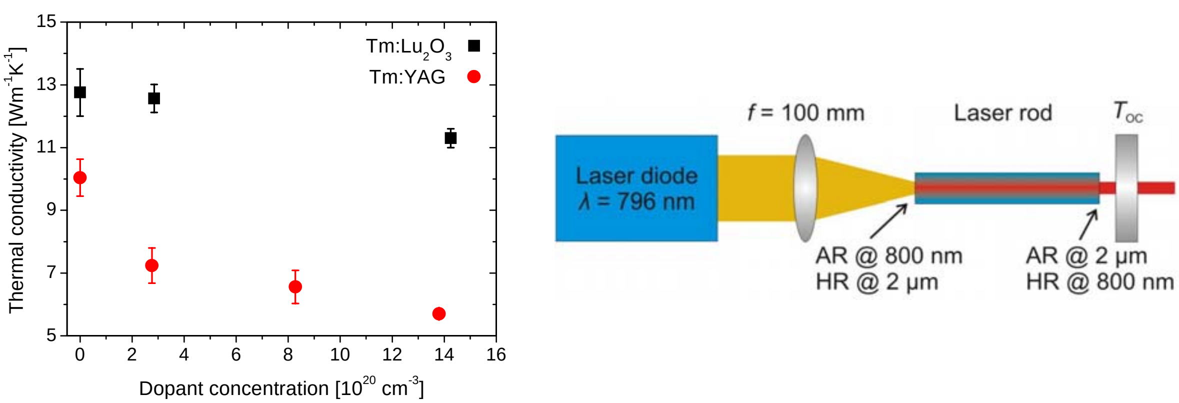

Fig. 1: (a) Thermal conductivity versus Tm^{3+}-density in $Tm:Lu_2O_3$ and Tm:YAG; (b) Schematic of the laser resonator

3. Laser Experiments

For the laser experiments a very simple setup has been used, as can be seen in Fig. 1 b. A laser diode with a maximum output power of 110 W at a wavelength of 796 nm served as the pump source. The pump light was focused into the crystal with an *f* = 100 mm lens. On the incoupling side the crystal was AR coated for the pump and HR coated for the laser wavelength, on the outcoupling side it was vice versa. Therefore a double pass of the pump light was achieved. The barrel-polished 15 mm long crystal was mounted into a pump chamber and surrounded by water with exception of the in- and outcoupling-facets. Crystal diameters of 2 and 2.5 mm were examined. The water temperature was kept at 19 °C.

The plane outcoupling mirror was placed as close to the crystal as possible. Several different transmissions between 0.8 % and 23 % were tested. The resulting input/output curves for a crystal rod with 2.5 mm in diameter are shown in Fig. 2 a. Using the 2 mm rod similar results were achieved.

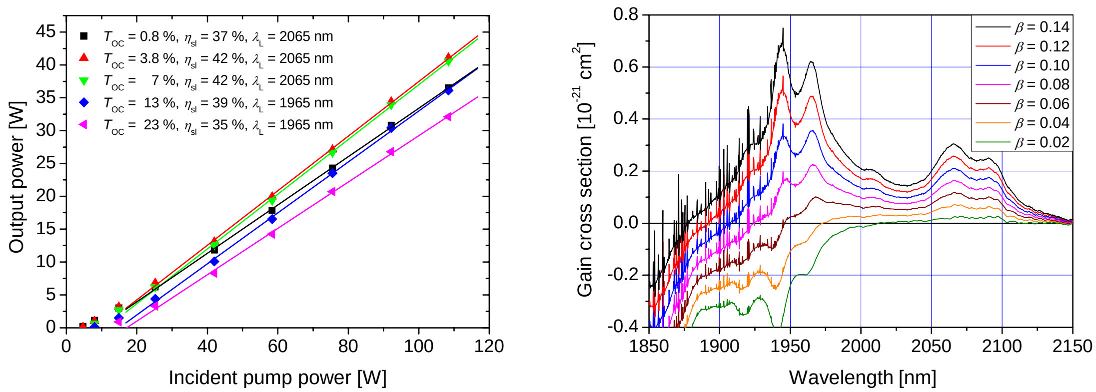

Fig. 2: (a) Output power versus incident pump power for a 15 mm long crystal with 2.5 mm in diameter;
(b) Gain spectrum of $Tm:Lu_2O_3$ for different inversions

The maximum output power was 41 W, the laser threshold was around 4 W for low outcoupling rates. Depending on the transmission of the output coupler, slope efficiencies between 35 % and 42 % were observed. The maximum slope efficiency could be achieved with 3.8 % and 7 % of outcoupling. For higher outcoupling rates a decrease of the slope efficiency could be observed which supposably is mainly due to increasing upconversion losses because of the higher inversion density. The higher inversion is also the reason for the change of the laser wavelength from about 2065 nm to 1965 nm when increasing the outcoupling from 7 % to 13 %. The change of the gain spectrum for increasing inversions can be seen in Fig. 2 b.

About 90 % of the incident pump power were absorbed in the crystal, leading to a maximum slope efficiency of 46 % with respect to the absorbed power.

4. Summary

We reported the first diode pumped laser operation of $Tm:Lu_2O_3$ at 2 µm with more than 40 W of output power and slope efficiencies of up to 42 % at room temperature. In comparison to Ti:sapphire pumped experiments an approximately equal performance could be achieved. For the future experiments with higher dopant concentrations are planed, which should lead to even higher slope efficiencies [2].

5. References

[1] T. V. Fan, G. Huber, R. L. Byer, P. Mitzscherlich, “Spectroscopy and Diode Laser-Pumped Operation of Tm, Ho:YAG,” IEEE J. Quantum Electron. **24**, 924-933 (1988).

[2] P. Koopmann, R. Peters, K. Petermann, and G. Huber, “Highly Efficient, Broadly Tunable $Tm:Lu_2O_3$ Laser at 2 µm,” in Proceedings of CLEO Europe – EQEC 2009, # CA10.3 THU (2009).

[3] K. Petermann, G. Huber, L. Fornasiero, S. Kuch, E. Mix, V. Peters, S.A. Basun, “Rare-earth-doped sesquioxides,“ J. Lumin. **87-89,** 973-975 (2000).

[4] P. G. Klemens, “Thermal Resistance due to Point Defects at High Temperatures,” Phys. Rev. **119,** 507-509 (1960).