Diode-pumped $Tm{:}Lu_2O_3$ thin disk laser

M. Schellhorn[1], P. Koopmann[2,3], K. Scholle[2], P. Fuhrberg[2], K. Petermann[3], and G. Huber[3]
1) French-German Research Institute, ISL, 5, rue du General Cassagnou, 68301 Saint-Louis, France
2) LISA laser products, Max-Planck-Str. 1, 37191 Katlenburg-Lindau, Germany
3) Institute of Laser-Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

martin.schellhorn@isl.eu

Abstract: We report the first diode-pumped $Tm{:}Lu_2O_3$ laser operation in thin disk design. Average output powers of 1.4 W and slope efficiencies of 32 % with respect to incident pump power were achieved in quasi-CW pumping.

OCIS codes: (140.3480) Lasers, Diode Pumped; (140.3410) Laser Resonators

1. Introduction

Lasers emitting in the wavelength range around 2 µm are useful for a variety of scientific and technical applications, including remote sensing, gas detection and medicine. Depending on the host, the laser wavelength of thulium-doped crystals lies between 1.8 and 2.1 µm. Thulium has high absorption peaks conveniently located for diode pumping around 800 nm and exhibits a cross-relaxation process which creates two ions in the upper laser level for each pump photon absorbed.
As a host for the thulium ion Lu_2O_3 exhibits excellent properties: broad emission spectra, high emission cross sections, an effective cross relaxation process and a high thermal conductivity which only slightly decreases with increasing doping concentration due to the low difference in masses of thulium and lutetium. However, the growth of high quality Lu_2O_3 bulk crystals is complicated due to the high melting temperature of Lu_2O_3 above 2400 ºC. Using a Ti:sapphire laser as the pump source the first continuous-wave (CW) laser operation of a 5 at.% doped $Tm{:}Lu_2O_3$ crystal was demonstrated and output powers of 1.5 W with slope efficiencies of up to 61 % with respect to absorbed pump power were achieved [1]. Using a 1 at.% doped $Tm{:}Lu_2O_3$ crystal the first diode pumped laser operation with more than 40 W output power and slope efficiencies of up to 42 % with respect to the incident pump power were obtained at room temperature [2]. Laser operation of thulium in thin disk design was reported by Diening et al using a 6 at.% doped Tm:YAG disk [3]. A maximum CW output power of 4 W at a heat sink temperature of -17 ºC was achieved.
In this paper we present preliminary results of a diode-pumped $Tm{:}Lu_2O_3$ laser in thin disk design. Average output powers of 1.4 W and slope efficiencies of 32 % with respect to incident pump power were achieved in quasi-CW (QCW) pumping. However, pumping the thin disk in CW mode, we observed a remarkable increase of the laser threshold and a reduced slope efficiency. True CW laser operation was even limited to pump power levels of up to 5 W due to thermal effects.

2. Experimental Setup

A 5 at.% doped $Tm{:}Lu_2O_3$ crystal boule was grown by the heat exchanger method at the ILP of the University of Hamburg. Thin disks with a diameter of 5 mm have been extracted from the boule and polished. In the experiments we used disks with a thickness of 200, 300 and 500 µm. The back side of each crystal had a coating with high reflectivity (R > 99.8 %) at the lasing wavelength range between 2000 and 2100 nm at normal incidence and high reflectivity (R > 99.5 %) at an angle of incidence between 12 and 26 degrees for the pump wavelength of 796 nm. This side was mounted on a water-cooled copper heat sink and the cooling water temperature was kept at 17ºC. The other side of each crystal was antireflection coated for the pumping (R < 0.2 %) and lasing (R < 0.2 %) wavelengths. A 40 W fiber coupled diode module (LIMO40-F200-DL808(MED635)-EX1000) connected with a fiber with a core diameter of 600 µm and NA = 0.2 was used as the pump source. The temperature of the diode module was set to 27 ºC. The pump wavelength increases slightly from 794 nm at threshold to 797.5 nm at maximum pump laser power to match the main absorption peak of $Tm{:}Lu_2O_3$ at 796 nm. A commercial TGSW (Technologiegesellschaft für Strahlwerkzeuge, Stuttgart, Germany) thin disk laser module was used to pump the $Tm{:}Lu_2O_3$ crystal. This module consists of a parabolic mirror with f = 32.5 mm and four folding mirrors with high reflectivity (R > 99.8 %) to form a pump beam which passes the crystal 24 times. That enables efficient absorption of the pump light which we calculated to be in the range of 70 – 90 %. A lens system with a focal length of 25 mm was used behind the fiber to collimate the pump beam before entering the thin disk laser module. The pump spot diameter on the disk has been measured with a CCD camera to be ~ 740 µm. The laser emission performances were investigated in a plano-concave resonator with an output coupler with a radius of curvature of 200 mm and a resonator length of 65 mm.

3. Experimental Results

The first experiments have been carried out in QCW pumping regime with a pump pulse duration of 10 ms and a duty cycle of 25%. Figure 1 shows the average output power as a function of the average pump power for different transmissions of the output couplers T_{OC} obtained with a (a) 500 µm thick, (b) 300 µm thick and (c) 200 µm thick $Tm:Lu_2O_3$ disk. In all cases the laser operated at a wavelength of 2065 nm and the best laser performance was achieved with an output coupler with T_{OC} = 0.8 %. With the 500 µm thick crystal the highest average output power was 1.4 W at a pump power level of 5.1 W. A deviation from a linear increase of the output power is observed in any case. Slope efficiencies have been calculated in the linear regime. A maximum slope efficiency of 32 %, 26.6 % and 25.7 % was observed with the 500 µm, 300 µm and 200 µm thick crystals, respectively. The decrease of the slope efficiencies could be explained by the decrease of absorption of the pump light with decreasing thickness of the disks. A total absorption of 90 %, 82 % and 72 % was calculated for the 24 pass of the pump light through the crystals with a thickness of 500 µm, 300 µm and 200 µm, respectively.

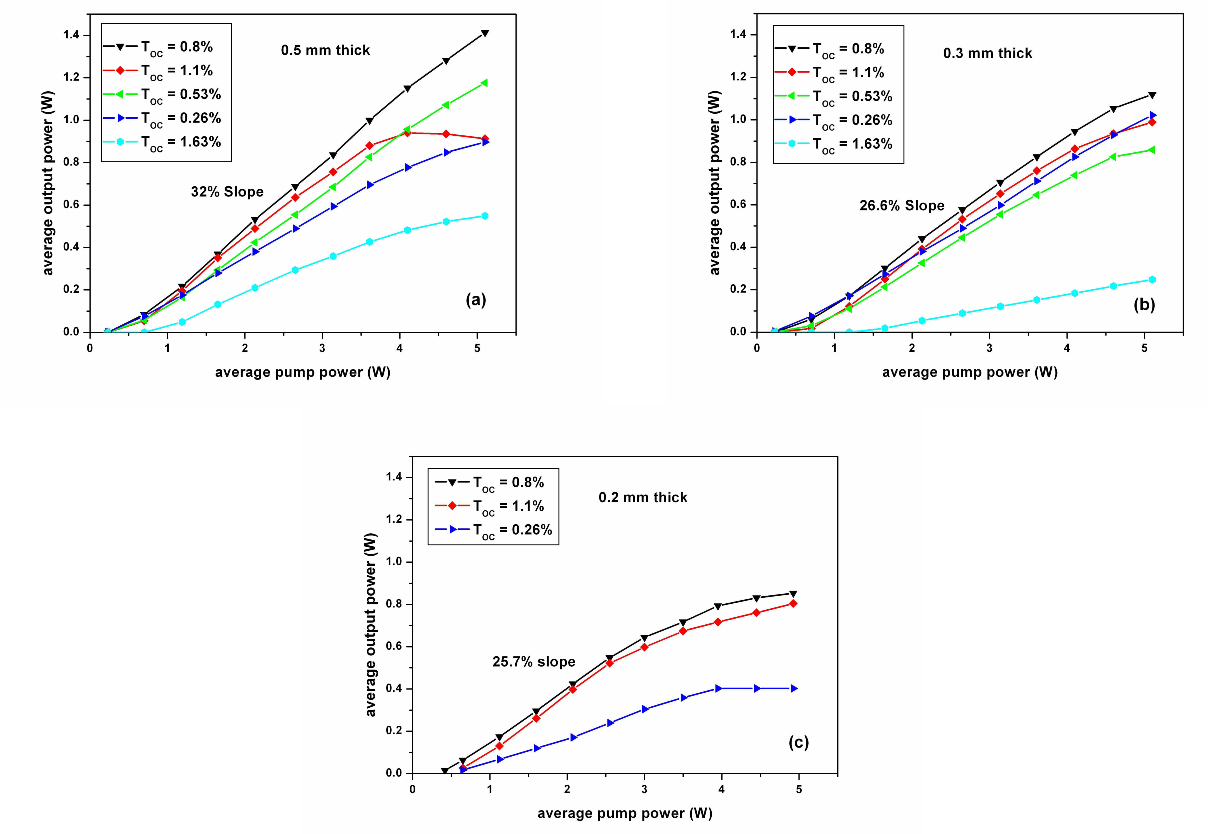

Fig. 1 Average output power in the QCW regime of the $Tm:Lu_2O_3$ thin disk laser as a function of average pump power with a disk thickness of (a) 500 µm, (b) 300 µm and (c) 200 µm. The duty cycle is 25%.

By evaluating the slope efficiencies in the linear regime of two other output couplings, 0.53 % and 0.26 % (500 µm thick crystal), one can fit the resonator losses as well as the intrinsic slope efficiency to the experimental points. Plotting the inverse of the slope efficiency versus the inverse of the output coupler transmission, also known as a Caird plot [4], a value of 0.3 % for the resonator losses and an intrinsic slope efficiency of 50 % (assuming an absorption of ~ 80 % of the pump power) have been found. This is a little higher than the quantum defect of $Tm:Lu_2O_3$ of 38 %, but taken into account that 2 ions in the upper lasing level could be created by 1 absorbed pump photon due to the cross relaxation process at this high doping concentration, a value of 77 % should be possible, in theory. It is evident that the lasing performance is very sensitive to the resonator losses because of the low output coupling of the thin disk laser. The resonator losses of 0.3 % are approximately 37 % of the optimum value of the output coupling of T_{OC} = 0.8 %. On the other hand it is well known that the upconversion process starting from the upper laser level of thulium doped hosts is essential for the dynamics of the system. This process limits the population of the upper laser level and thus the gain reachable in the material. But this upconversion is more severe for the thin disks due to their limited amplification length corresponding to a higher inversion density of the upper laser level [3].

ATuB14.pdf

Laser operation in the true CW regime is possible and the laser performance of the $Tm:Lu_2O_3$ disk with a thickness of 300 µm is shown in Fig. 2 together with the results obtained in the QCW regime with 25 % and 50 % duty cycle. We observed higher laser thresholds and lower slope efficiencies with an increase of the duty cycle. True CW operation was only possible up to a pump power level of 5 W.

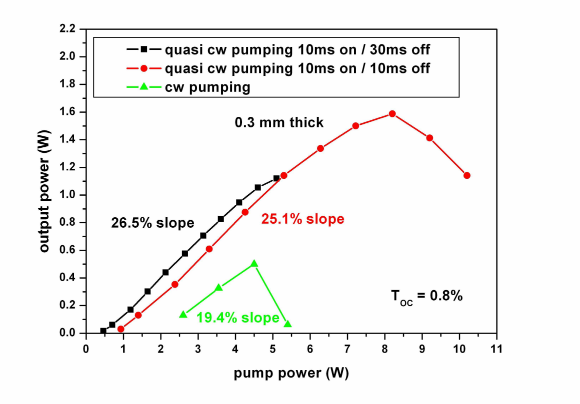

Fig. 2 Output power in the true CW regime and QCW regime with 25 and 50 % duty cycle of the $Tm:Lu_2O_3$ thin disk laser as a function of average pump power with a disk thickness of 300 µm and output coupling of T_{OC} = 0.8%.

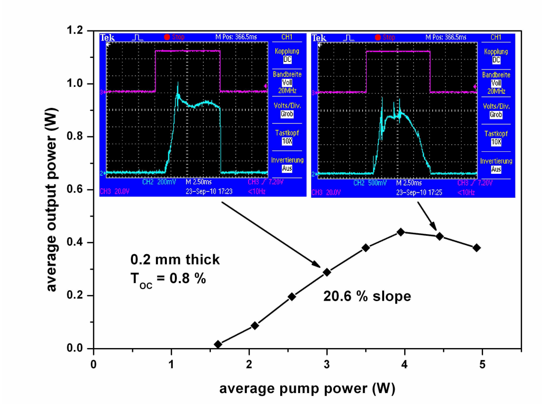

Fig. 3 Average output power in QCW regime with a duty cycle of 25 % as a function of average pump power with a disk thickness of 200 µm and output coupling of T_{OC} = 0.8%. The resonator length is 210 mm. The insets show the pump pulse (pink) and the laser power signal (blue) as a function of time.

We observed a remarkable formation of a thermal lens even at low pump power levels. With the 200 µm thick $Tm:Lu_2O_3$ disk we extended the resonator length to 210 mm. With the curvature of the output coupler of 200 mm the resonator is unstable and only becomes stable if the focal length of the thermal lens in the $Tm:Lu_2O_3$ disk is shorter than the resonator length. We observed QCW laser operation as can be seen in Fig. 3. The insets show the temporal behavior of the pump and laser power at two different pump power levels. With this resonator configuration the laser threshold is increased to ~ 1.6 W. At this point the focal length of the thermal lens should be around 200 mm and the laser resonator becomes stable and laser operation starts. With higher pump power the delay of the laser power signal with respect to the pump pulse becomes shorter due to the faster built-up time of the thermal lens. At pump power levels exceeding 4 W the laser power signal decreases at the end of the pump pulse resulting in the roll over of the measured average output power. Since this resonator configuration should be stable up to much shorter focal lengths of the thermal lens, this effect indicates that the laser gain drops significantly with increasing temperature of the disk.

4. Summary

We obtained an average output power of 1.4 W and a slope efficiency of 32 % with respect to incident pump power in QCW pumping of a 5 at.% doped $Tm:Lu_2O_3$ thin disk laser at a wavelength of 2065 nm. True CW operation was possible but we observed a higher laser threshold, a lower slope efficiency of ~ 19 % and CW operation was limited to a pump power of 5 W. This roll over indicates that the laser gain drops significantly with increasing temperature of the disk.

5. References

1. P. Koopmann, R. Peters, K. Petermann, and G. Huber, "Higly efficient, broadly tunable $Tm:Lu_2O_3$ laser at 2 µm", in Proceedings of the European Conference on Lasers and Electro-Optics (CLEO_E) 2009, paper: CA10.3 (2009).
2. P. Koopmann, S. Lamrinr, K. Scholle, P. Fuhrberg, K. Petermann, and G. Huber, "High power diode pumped 2 µm laser operation of $Tm:Lu_2O_3$", in Proceedings of the Conference on Lasers and Electro-Optics (CLEO) 2010, paper: CMDD1 (2010).
3. N. Berner, A. Diening, E. Heumann, G. Huber, A. Voss, M. Karszewski, and A. Giesen, "Tm:YAG: a comparison between endpumped laser-rods and the thin-disk-setup", OSA TOPS Vol. 26 Advanced Solid-State Lasers, M. M. Fejer, H. Injeyan, U. Keller (eds.), Optical Society of America, 463 (1999).
4. J. A. Caird, S. A. Payne, P. R. Staver, A. J. Ramponi, L. L. Chase, and W. F. Krupke, "Quantum electronic properties of the $Na_3Ga_2Li_3F_{12}:Cr^{3+}$ laser", IEEE J. Quantum Electron. **24**, 1077 (1988).