High-efficient Tm^{3+}:$LiLuF_4$ thin-disk laser

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Abstract: We report the first diode-pumped Tm^{3+}:$LiLuF_4$ laser operation in thin-disk design. A maximum output power of 21 W at 1.9 µm and a maximum slope efficiency of 49 % were achieved with continuous pumping.

OCIS codes: (140.3070) Infrared and far-infrared lasers; (140.3480) Lasers, diode-pumped

1. Introduction

Laser sources between 1.9 - 2 µm are suitable in medical and industrial applications and can also be used as pump sources. The first 2 µm thin-disk laser was realized with Tm^{3+}:YAG [1] as active material in 1999. Due to the fact of the necessity of a high pump absorption after several pump round trips through the thin active material the doping level of the active material should be high or the thickness of the thin-disk has to be increased which leads to strong thermal effects. The laser material Tm^{3+}:YAG can only be doped with 2 - 4 % to favor the cross-relaxation process which allows pumping around 800 nm to obtain 2 µm emission and avoid strong upconversion. This low doping level results a thicker disk and leads to a strong thermal effect which limits efficient laser operation. Another possibility to run a 2 µm thin-disk laser is using Holmium instead of Thulium which was shown in 2006 with Ho^{3+}:YAG [2] pumped at 1.9 µm and emitting at 2.09 µm, which leads to a very low quantum defect. For doping concentrations higher than 1 % in Ho^{3+}:YAG upconversion starts dominating and limits the laser operation. In 2011 [3] the very promising material Tm^{3+}:Lu_2O_3 was demonstrated in thin-disk design which was pumped at 796 nm for a laser emission at 2.06 µm. In the used setup this laser has shown unexpected behavior which resulted in low output power and comparatively low slope efficiency. Another promising host material for Thulium was demonstrated in 2008 [4] where doping levels up to 16 % have shown no parasitic upconversion. One of the big advantages in this material is the relatively broad absorption spectrum around 792 nm which makes it easier to pump with commercial diode lasers. In this report we present the first Tm^{3+}:$LiLuF_4$ thin-disk laser based on high Tm^{3+} doping concentrations.

2. Experimental setup

For the thin-disk experiments we used continuous pumping with a diode of 23 W (diode A) which had a small emission line width of < 2 nm and a pump diode with 100 W (diode B) output power at 795 nm at a line width of < 3 nm. Diode A shifted from 793.5 nm at threshold to 797 nm at maximum pump power. For diode B the wavelength range extended from 789 nm to 795 nm at maximum output power which matches the highest pump absorption for Tm^{3+}:LLF_4. All used output couplers had a curvature of R = 0.2 m and showed slightly decreasing transmission between 1.9 µm and 1.94 µm (Fig. 1 a)). The disk module is constructed for 24 pump passes through the disk and was put in a box flushed with dry air where the relative humidity could be set to rH = 3 % which was necessary to obtain maximum output power due to strong water absorption at the laser wavelength. The cavity length was 116 mm which gives a long stability region for negative and positive curved thin-disks. For our measurements the used Tm^{3+}:LLF_4 was grown at the University of Pisa with a doping concentration 12 % at.. The thin-disks had a diameter of 6 mm with a thickness of ~ 250 µm and polished on both sides. The front side was AR-coated for the pump around 795 nm and the laser emission at 1.9 µm and the back side was high reflective for both wavelengths (R > 99.9 %). The thin-disks were soldered by [5] on a gold coated copper-tungsten alloy heat sink. The water temperature for cooling the disk module was T = 20°C. As the absorbed pump power could not be determined, we quote our results with respect to the incident pump power entering the thin-disk laser module, displayed in Fig. 1.

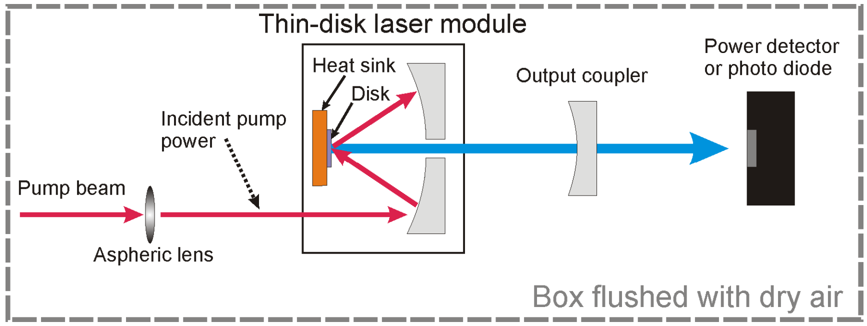

Fig. 1. Schematic drawing of the Tm^{3+}:LLF_4 thin-disk laser setup.

3. Experimental results

For the experiments one aspheric focusing lens was used to create a homogenous pump spot on the disk. The pump spot was measured to 1.63 mm with a CCD camera using the pump diode A with three different output couplers (Fig. 2 a)). A slope efficiency of 49 % and an output power of 8.7 W at 22 W of pump power was obtained with output coupler A (OC A). The transmission curves for all the output couplers and the measured wavelength peaks are shown in Fig. 2 a). After 18.5 W of incident pump power the slope of the power curve starts smoothly decreasing which is not a thermal effect inside the crystal but caused by the falling edge of the absorption cross section of Tm^{3+}:LLF_4. Due to the complex coupling between overall pump absorption, crystal absorption and resulting number of pump passes a maximum pump wavelength of 795.5 nm was deduced, above this the laser efficiency decreases.

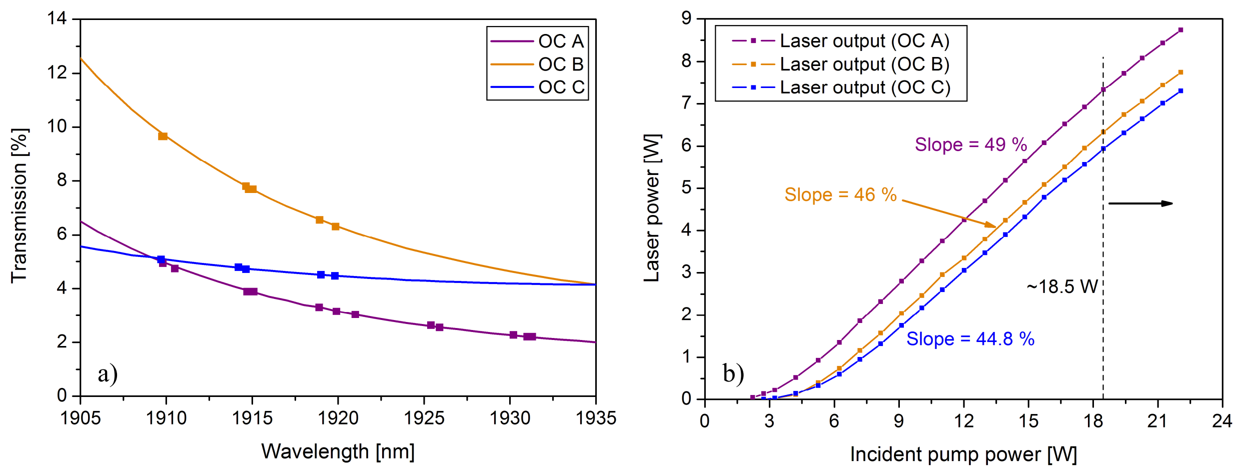

Fig. 2. a) Output coupler transmission with the measured wavelength peaks and b) the output power of the Tm^{3+}:LLF_4 laser for the three output couplers pumped by diode A.

In Fig. 3 a) we increased the pump spot to 3.26 mm at the same disk as in Fig. 2 b) and used diode B. Unfortunately the slope efficiency was lower than before and after damaging the disk we have seen a small not well contacted HR-coating area on the back side of the disk in the pump spot region. However 21 W of output power at 1.91 µm at 100 W pump power of diode B was achieved. After searching the reason of the damage and how to prevent this kind of damage a second disk was used to pump again with a 1.63 mm pump spot but with the temperature tuned diode B to get high absorption over the whole pump regime. With the second disk and the output coupler C (OC C) a slope efficiency of 46.4 % and 12.3 W of output power at 32.2 W of pump power was achieved which corresponds to a pump intensity of 1.5 kW/cm². The optical-to-optical efficiency reached 38.2 % with OC C. In Fig. 3 b) the measured emission spectrum is shown for the second disk around laser threshold and the pump power of 32.2 W. The emission shifts slightly to higher wavelengths by increasing the pump power. The distance of the two main wavelength peaks corresponds very precisely to the etalon effect of the thin-disk.

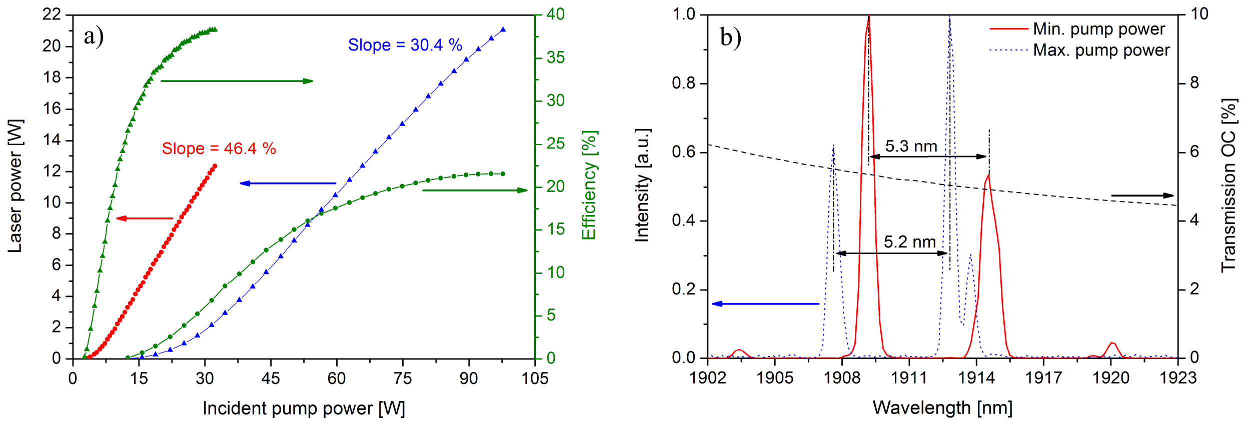

Fig. 3. Power and efficiency curves a) from two different disks and pump spots and the emission spectrum b) of the disk with 45.4 % slope efficiency.

During laser operation a fast InGaAs photo diode was used to detect power fluctuations or self modulation in the output but none of these effects was seen during operation which is usually observed with quasi-cw pumped Thulium system. Due to the fact of the long stability region of the used short resonator setup we calculated the mode radius for the fundamental mode to 250 µm which would correspond to a $M^2 \sim 11$ in case the whole pump area would be filled up by these modes. At the maximum output power the M^2 was measured to $M^2_x = 9.8$ and $M^2_y = 11.8$. We also used a HeNe-laser to test for some optical influences due to the thermal changes in the disk by increasing the pump power but the reflected HeNe spot showed no detectable changes.

4. Summary

Thulium doped $LiLuF_4$ as a thin-disk material for wavelengths at 1.9 µm has shown very promising results. Pumping with commercial pump diodes around 792 nm we achieved a slope efficiency of 49 % with Tm^{3+}:LLF_4 in thin-disk design. At Pump intensities of 1.5 kW/cm² we reached 12 W with 1.63 mm and 21 W with a 3.26 mm pump spot diameter. The laser emitted at 1.91 µm and was only slightly shifting with increasing pump power. The laser output was stable and we have not seen any induced self modulation during continuous pumping and no strong thermal effects were detected.

5. References

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