2 µm Ho:YAG Thin Disk Laser

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Abstract: A Thulium fiber laser pumped Ho:YAG thin disk laser with 15W (cw) or several mJ (pulsed) operation will be presented. Additionally, a narrow (<0.5nm), tunable (30nm) cw operation near 2.09 µm, will be shown.

OTIC codes: (140.3460) Lasers, (140.3070) Infrared and far-infrared lasers.

1. Introduction

Continues-wave 2 µm laser show applications in the 'eye-safe' wavelength range, e.g., laser material processing, laser welding of transparent plastic materials as well as laser surgery or therapy. Furthermore, a pulsed-mode operation of a 2 µm laser opens up the mid-infrared region via pumping of an optical parametric oscillator based on nonlinear crystals like zinc germanium phosphide ($ZnGeP_2$) or orientation-patterned GaAs to efficiently produce radiation in the 3 µm – 12 µm spectral range. For gas monitoring or remote sensing, the tunable 2 µm laser can be operated in the wavelength range of CO_2 molecules to detect footprints of their vibrational bands [1].
The larger emission cross section of the Ho^{3+}-system at 2.09 µm compared to Tm^{3+}-systems makes the Ho:YAG thin disk laser concept with its inherent low gain per pass in a multiple pump pass concept [2] attractive for the generation of high power in cw- or pulsed-mode operation. Pumping the Ho $^5I_7$ manifold laser based on the YAG host material with a Tm:YLF or Tm fiber laser at 1.908 µm offers the advantage of high efficiencies and reduced heating due to an inherent low quantum defect of less than 6% between the pump and laser wavelength.
In 2006, Martin Schellhorn published his results about the 'performance of a Ho:YAG thin-disc laser pumped by a diode-pumped 1.9 µm thulium laser' [3]. In his investigation the pump beam spot size was varied between 0.9 mm and 1.7 mm. A cw output power of 9.4 W was accomplished with an optical to optical efficiency of 36%.
In the present report a single mode Thulium fiber laser at 1.908 µm will be used to pump a Ho:YAG thin disk laser in a multi-pass pumping scheme via a multimode transfer fiber to generate a flat pump intensity distribution on the disk. With a 24 pump pass concept an efficient absorption of the pump light in the Ho:YAG disk material is achieved. A telecentric imaging is applied to assure a relatively constant pump beam distribution [4].

2. Experimental setup and results of the cw or pulsed Ho:YAG thin disk laser

The layout of the cw or pulsed thin disk laser is shown in figure 1, schematically.

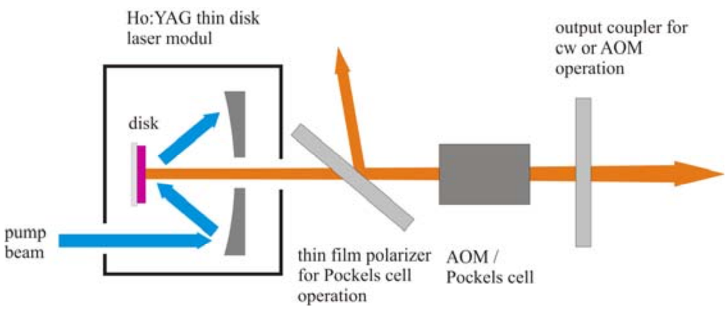

Fig. 1. Schematic diagram of the cw or pulsed Ho:YAG thin disk laser system.

The single mode fiber laser pump beam (IPG, 50 W) is focussed into a 600/660 µm polyimide transfer fiber before entering the disk laser module (Dausinger + Giesen GmbH). With a pair of collimating lenses the pump beam is transferred onto the parabolic mirror optics for the 24 pump passes. The operation of the disk laser was investigated for two different disks. The Ho in YAG concentration of disk 1 was 2%, with a disk thickness of 400 µm and a disk diameter of 5 mm. The disk 2 had a 1.6% concentration, a 400 µm disk thickness and a 4 mm disk diameter. The Ho:YAG crystal coating was designed to have a high reflectivity (R > 99.8%) at the lasing wavelength of 2.09 µm and a high reflectivity (R > 99.5%) at an angle of incidence between 12° and 26° for the pump wavelength of 1.908 µm. The front side of the disk was antireflection coated for the pumping (R < 0.4%) and lasing (R < 0.1%) wavelengths. The pump beam spot

size on the disk was adjusted to a diameter of approximately 2 mm. The resonator length was varied between 10 and 30 cm and the output coupling of the flat mirrors could be changed from 0.5 to 3% in steps of approximately 0.5%. Due to the soldering of the Ho:YAG disks onto the copper heat sinks and the different coatings on both sides, the disks ended up showing a bended surface with a concave radius of curvature between 2 and 3 m. Disk lasers show in general a low thermal lens behaviour and therefore stable resonator configurations are possible for a wide resonator parameter range.
The output power of the cw Ho:YAG thin disk laser pumped with a Tm fiber laser is shown in figure 2. For a pump power of almost 47 W (1.5 kW/cm^2) the output power reached 15 W with a maximum efficiency of 37%. It can be recognized that the output power still shows a linear power scaling dependence. For an output power of 5 W the measurement of the beam quality yielded an M^2 of 2 at a 10 cm resonator length. Furthermore, the maximum of the output power was reached for an output coupling of 1.5%.

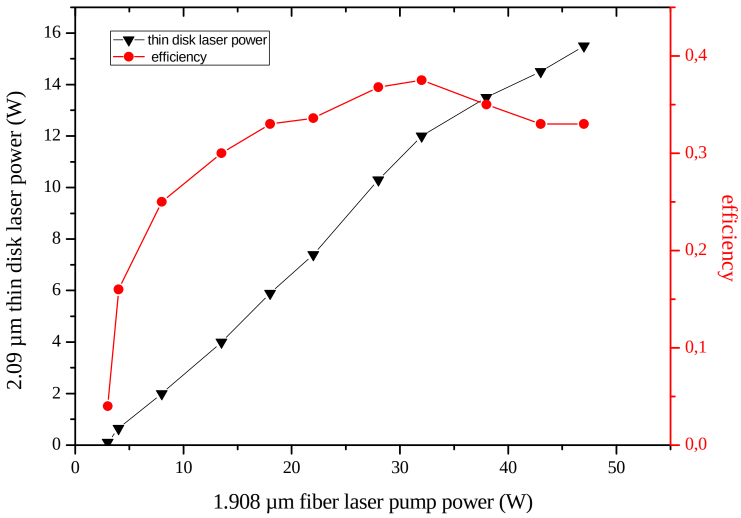

Fig. 2. Output power of the 2.09 µm cw Ho:YAG thin disk laser versus the 1.908 µm fiber laser pump power with an Ho in YAG concentration of 2% and an output coupling of 1.5%.

The operation of the Ho:YAG thin disk laser with an Ho in YAG concentration of 2 % in an acousto-optically switched mode (Gooch&Housego, QS027) showed output pulse energies up to 3 mJ for repetition rates in the lower kHz-range (see figure 3).

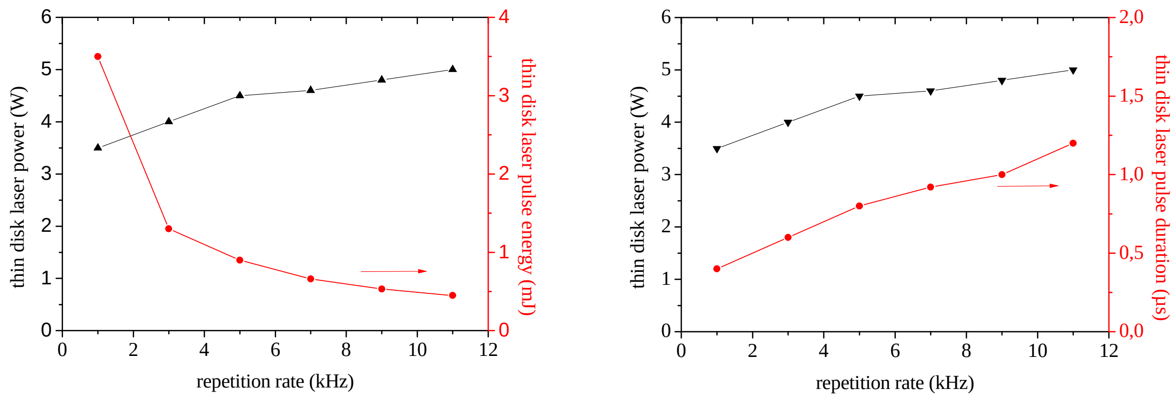

Fig. 3. Pulsed operation of the Ho:YAG thin disk laser (2% Ho in YAG) with an acousto-optical modulator.

The pulse duration increased from 0.4 up to 1 µs for repetition rates between 1 and 10 kHz. In the acousto-optically switched operation and with a pump power in the order of 50 W, local damage occurred on the disk coating and YAG material. With a reduced pump power (20 W) and disk 2 (1.6% Ho in YAG concentration) a pulse energy of 1.4 mJ at 1 kHz has been reached. Furthermore, a Pockels cell switched operation (Raicol, RTP) was investigated, too. The output pulses showed similar pulse durations compared to the acousto-optically switched performance. The relatively long pulse lengths obtained are mainly due to the long lifetime of the upper state of Ho in YAG with approximately 8 ms.

3. Tunable, narrow bandwidth operation of the Ho:YAG thin disk laser

For wavelength tuning the cw Ho:YAG thin disk laser was operated with a birefringent filter (Lyot, B. Halle GmbH) consisting of two Brewster angle tilted quartz plates with thicknesses of 2 and 8 mm. Without the Lyot filter the oscillator showed two lines with a separation of roughly 5 nm. Including the Lyot filter the spectrum was reduced to a narrow, single line with a bandwidth of less than 0.5 nm measured with a monochromator (Yvon-Jobin, resolution 0.5 nm). For the narrow, single line operation the output power reached more than 1 W. In figure 4, the tunable, narrow, single line thin disk laser output is shown compared to the emission cross section of Ho:YAG (NASA database). For wavelengths below 2.076 µm and above 2.102 µm the output falls off due to a lower gain compared to the loss in the resonator.

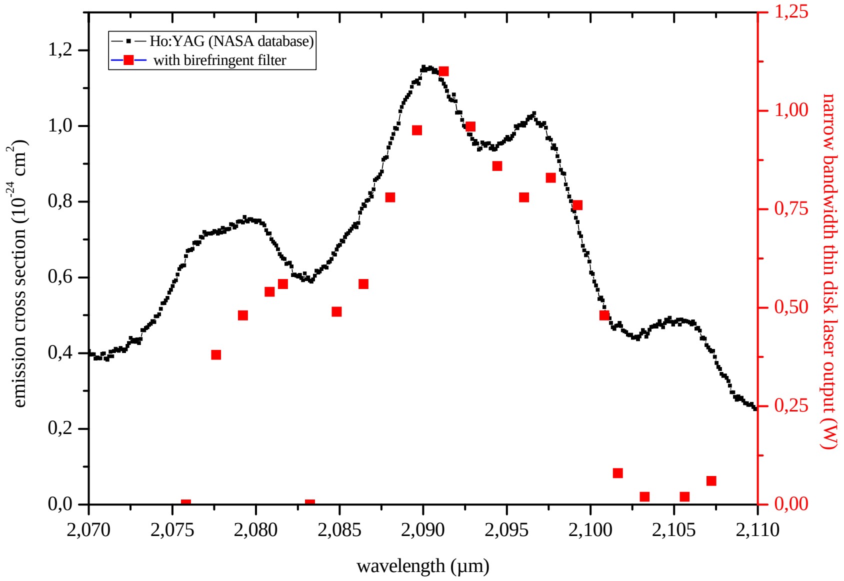

Fig. 4. Tuning curve of the cw Ho:YAG thin disk laser with a birefringent filter and the emission cross section (NASA database).

4. Conclusions

Holmium doped YAG is a promising laser material for thin disk lasers in the 2 µm range. A cw laser output power of 15 W has been realized with an efficiency of 37% for a Ho in YAG concentration of 2% with scaling opportunities to higher power. Pulsed-mode operation in the kHz-range with pulse energies in the mJ-range was also demonstrated. Compared to the acousto-optically switched operation a Pockels cell switched configuration showed similar pulse lengths behaviour. Installing a birefringent filter into the resonator, a cw laser output power in the order of 1 W with a narrow bandwidth, single line (< 0.5 nm) and a tuning range of 30 nm close to 2.09 µm has been realized. In a further step the narrow bandwidth pulsed laser output will be amplified by a regenerative amplifier system to higher output powers.

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5. References

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