Q-switched Tm^{3+}:YAG Rod Laser with Crystalline Fiber Geometry

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Abstract: We present experimental results on TIR-pumped Q-switched Tm^{3+}:YAG lasers pumped at 804 nm. Up to 5.6 mJ pulse energy is achieved (25.9 kW peak power at 216 ns pulse width).

OCIS codes: (140.3540) Lasers, Q-switched; (140.5680) Rare earth and transition metal solid-state lasers

1. Introduction

Near-infrared pulsed 2 µm lasers are important laser sources for various applications in spectroscopy, range detection, optical countermeasures and especially for medical applications and as pump sources for mid-infrared optical parametric oscillators (OPO). Mostly, Q-switched Ho:YAG lasers are used as this laser medium provides a high cross-section for stimulated emission and therefore a low-to-medium saturation fluence of ~ 7 J/cm^2, being within the capabilities of standard dielectric coatings. However, direct diode pumping at around 1.9 µm is still very expensive, making directly diode pumped Tm lasers, emitting around 2 µm and which can be pumped with inexpensive 804 nm laser diodes, an alternative that is worth being investigated. One candidate, i.e. Tm:YALO, has been efficiently used for this purpose at high repetition rates [1]. But this material is birefringent and shows strong thermal lensing effects that prevent it from being used for low-repetition-rate high-pulse-energy applications. The isotropic Tm:YAG seems to be more suited for this case, for which 2.4 mJ pulse energy have been achieved by electro-optic RTP Q-switching [2]. Nevertheless, the high saturation fluence of Tm:YAG of ~ 62 J/cm^2 will make it difficult to achieve a high-pulse-energy Q-switched operation and a good extraction efficiency, i.e. a high-over-all laser efficiency [3]. For some applications, especially in medicine, where the 2.01 µm radiation can either be directly used or converted to ~ 6.45 µm for minimally invasive surgery using an OPO, only average powers on the order of 1-10 W are necessary at pulse repetition frequencies of around 100 Hz, making the Tm:YAG laser an interesting candidate. In a recent work on electro-optically Q-switched Tm:YAG, 4 mJ of output energy have been achieved with a short-length rod laser [4]. In this paper we report on a TIR-pumped Tm:YAG laser in pulsed-pumped quasi-cw and Q-switched operation.

2. Experimental results

The experimental setup uses barrel-polished Tm:YAG rods of 1.5 mm and 3 mm diameter and a doping concentration of 2 % Tm^{3+}. Due to the lower efficiency of the pulsed laser, coupled with the positive thermal lens of YAG, a specific laser design is necessary to provide good cooling of the laser crystal without creating a highly aberrated thermal lens. Therefore, the homogeneous pumping achieveable with total-internal-reflection (TIR) pumping is envisaged as allows an easier compensation of the thermal lens due to the mainly parabolically shaped thermal index profile, keeping aberrations low and allowing a good beam quality.

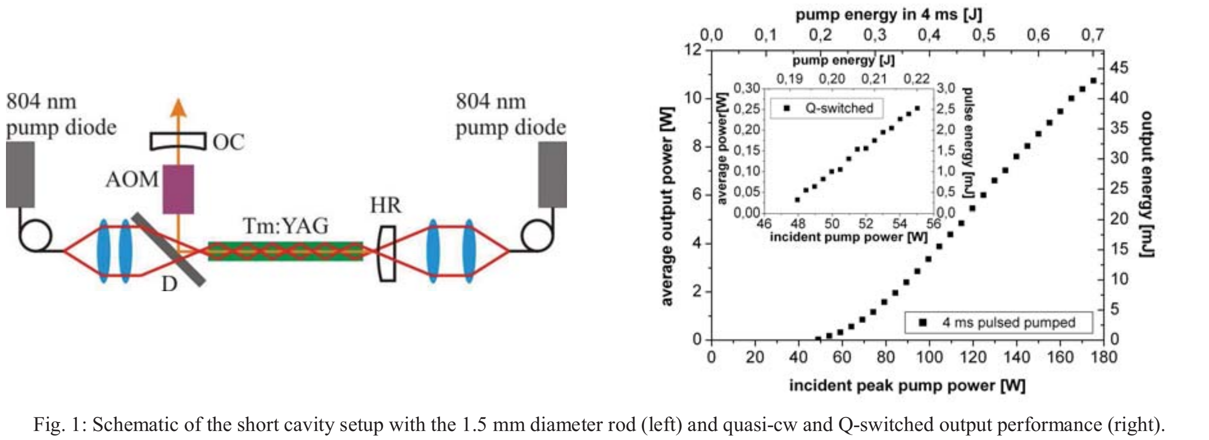

Fig. 1: Schematic of the short cavity setup with the 1.5 mm diameter rod (left) and quasi-cw and Q-switched output performance (right).

The 1.5 mm and 3 mm diameter rods are 80 mm and 90 mm in length, respectively, and possess 5 mm long undoped bonded end caps to reduce the end-face temperature. They are mounted in a silicone-sealed housing that allows direct water cooling of the outer barrel surface. The index difference between the water and the YAG crystal causes the TIR that is used for pump guiding. Two 200 µm core fiber-coupled laser diodes of 120 W output power each are used to pump the laser rods from both ends. As the fluorescence lifetime of Tm:YAG is ~ 12 ms, a pump pulse duration of 4 ms is chosen to keep a high pump efficiency. The setup and the output performance of the 1.5 mm rod is shown in Fig. 1. The 200 mm radius-of-curvature concave output coupler (OC) has a reflectivity of 80 % and the total cavity length is 180 mm. The HR mirror has a 300 mm convex curvature to compensate for the thermal lens. With the acousto-optic modulator (AOM) switched off, an average power of 10.8 W is achieved, corresponding to a free-running pulse energy of 43.2 mJ. In Q-switched operation only 2.53 mJ can be extracted before coating damage on the crystal occures, corresponding to 14.9 kW peak power at a pulse width of 170 ns at 100 Hz repetition rate. The slope efficiency in Q-switched operation is determined to 7.8 % with repect to the pump-pulse energy incident onto the crystal, while in quasi-cw operation a slope efficiency of ~ 10 % is observed. The lower slope in Q-switched operation is a direct consequence of the fact that an efficient extraction cannot be performed due to the high saturation intensity of the Tm:YAG medium.

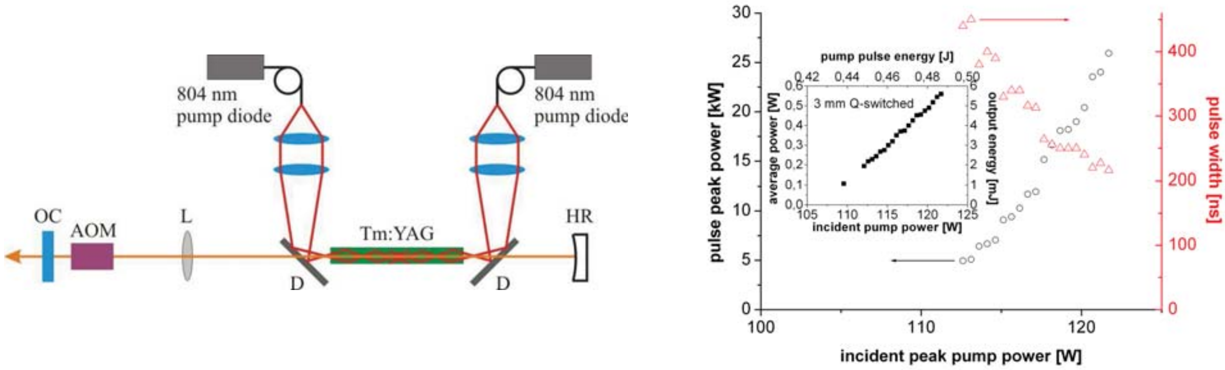

Fig. 2. Schematic of the long cavity setup with the 3 mm diameter rod (left) and Q-switched output performance (right).

In order to increase the output energy, the 3 mm diameter rod is used in the setup shown in Fig. 2. The cavity is lengthened to ~ 810 mm to decrease the intracavity fluence and a $f = 300$ mm lens L is inserted into the cavity to match the mode to the pumped medium. The HR mirror had a radius of curvature of 50 mm and a flat OC with 80 % reflectivity is used. Up to 14.5 W of average power is achieved with 4 ms pulsed pumping at 100 Hz in free-running mode. Q-switching results in an output energy of up to 5.6 mJ at a pulse width of 216 ns, corresponding to a peak power of 25.9 kW. The output pulses have a stable pulse shape which shows that the laser operates on the fundamental mode only. The slope efficiency in Q-switched operation is determined to 9.4 % with repect to the pump pulse energy incident onto the crystal, which is slightly higher than that obtained with the 1.5 mm rod diameter setup.

3. Conclusion

A TIR-pumped Q-switched Tm:YAG laser is presented, achieving up to 5.6 mJ of output pulse energy at 216 ns pulse width. The output performance, especially for small crystal diameters which enhance the laser efficiency due to higher pump intensity, is currently limited by coating damage. Further investigations will include the increase of output energy by an optimized cavity design, a determination and optimization of the beam quality and the nonlinear conversion of the 2.01 µm radiation in a ZGP OPO to obtain mid-infrared pulses around 6.45 µm.

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4. References

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