High power $Yb:Lu_2O_3$ dual-crystal laser

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Abstract: We present a dual-crystal $Yb:Lu_2O_3$ laser in CW and cavity-dumped regime. We obtained 19.5 W CW output power in a diffraction limited beam. When cavity-dumped, the output energy was limited to 3 mJ, owing to surface damage.

OCIS codes: 140.3615 (Lasers, ytterbium); 140.3538 (Lasers, pulsed); 160.3380 (Laser materials); 140.3580 (Lasers, solid-state)

1. Introduction

Ytterbium doped laser media are attractive for high power generation due to low quantum defect, lack of parasitic effects such as excited-state absorption, cross relaxation and up-conversion, leading to highly efficient and low heat load operation. In addition, most Ytterbium-doped materials provide emission linewidths that allow for fs-pulse generation. Among the newer Yb-doped host materials, Lu_2O_3 is very highly promising both in thin disk and bulk crystal geometry. Its thermal conductivity (12 W/mK) [1] is higher than that of Yb:YAG and broad band emission with a tuning range from of 987-1134.5 nm was demonstrated in continuous-wave regime [2]. Furthermore, mode-locked and continuous-wave operations in thin-disk laser geometry were shown with output powers of 7 W with 142 fs pulse duration [3] and 20.5 W with 370 fs [4], as well as 141 W with 738 fs pulse duration [5] and 670 W [6], respectively.

Here, we present the continuous-wave and cavity-dumped operation of dual crystal $Yb:Lu_2O_3$ laser with diffraction limited beam quality. The advantage of two distributed shorter crystals over one longer one lies in a more homogeneous longitudinal gain distribution and hence slightly higher gain, as well as lower thermal distortions at the pump entrance face [7]. The cavity design ultimately aims at the generation of multi-mJ (up to 10 mJ) sub-ps pulses at 1 kHz when operating as seeded regenerative amplifier. We show the cavity design, its CW performance and first results of unseeded cavity-dumped operation.

2. Experimental

The schematic of the resonator design is shown in Fig. 1. The two 1.5 mm long and 1.5% Yb-doped crystals are placed at Brewster's angle to either side of the symmetry point S. As per design, the mode waist radius in the crystal is 300 µm in vertical and 450 µm in horizontal direction. The pump is imaged to match the cavity mode. The cavity can be considered in three parts. Firstly, a short resonator is formed when placing a high reflector at the position S, forming a single crystal cavity. Secondly, after characterization of this resonator, the second crystal is added, with S becoming the cavity waist between the two crystals. Cavity mode analysis shows that this configuration is thermally rather insensitive in the mode at the end mirrors and in the crystals, whereas the variations at S are strong, but do not matter. Thirdly, in order to incorporate a Pockels cell, TFP and quarter-wave plate, the resonator is extended with a 4-f telescope in the way shown in Fig. 1. The two crystals are pumped by a single fiber-coupled (NA=0.2, 200 µm core size) pump diode delivering up to 120 W at 979 nm. However, the full power could not be used because the absorption peak of $Yb:Lu_2O_3$ lies at 976 nm and the diode temperature control could not provide the required cooling power.

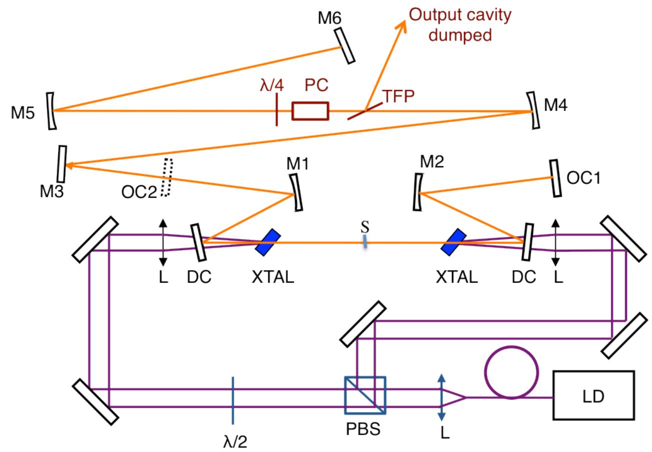

Fig. 1. Schematic of the dual crystal Lu_2O_3 laser setup. M are high reflecting mirrors, M1 and M2 have 500 mm radius of curvature, M4 and M5 have 1000 mm radius of curvature, OC are output coupling mirrors, S symmetry point, DC dichroic mirrors, PBS polarizing beam splitters, L lenses, λ/2 and λ/4 wave plates, PC Pockels cell, TFP thin film polarizer, LD laser diode.

3. Results

First, the short, single-crystal and the short, two-crystal cavities were characterized in CW operation. The low-power absorption was measured to be 79% in the crystal used for the single-crystal cavity characterization, and 67% in the other one. Figure 2a shows the output power of both resonators versus output coupling. The measurements were taken for the maximum pump power of 116 W. The beam profile was diffraction-limited. The maximal output power of 9.9 W in the single-crystal case was achieved with 5% output coupling, whereas the two-crystal cavity delivered 19.5 W for 10% output coupling. The shift of the maximum output powers to higher output couplers was, as expected, due to roughly twice the gain with two crystals compared with only one in the cavity. These settings were kept for the following measurements.

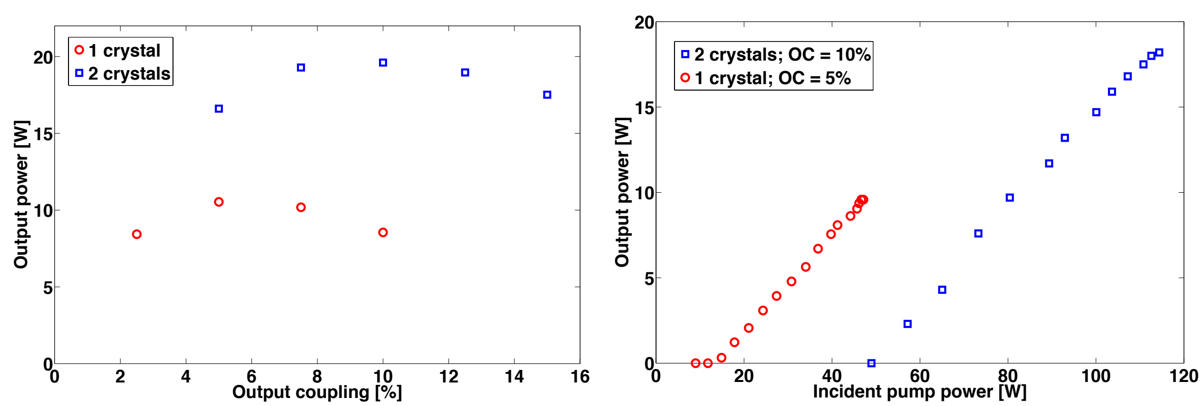

Fig. 2. Characterization of both cavities: Laser output power versus output coupling (a) and Laser output power versus incident pump power (b) for the short, single crystal cavity (red circles) and for the short, two-crystal cavity (blue squares).

The laser emission wavelength was 1034 nm for all output couplers but the 2.5% one, which allowed enough gain for the weaker 1080 nm line to lase simultaneously.

From Fig. 2b, displaying the laser output power versus total incident pump power, the slope efficiency of both cavities was determined to be 27% for the single-crystal cavity and 28% for the two-crystal one. The pump power thresholds were respectively 14 W and 54 W.

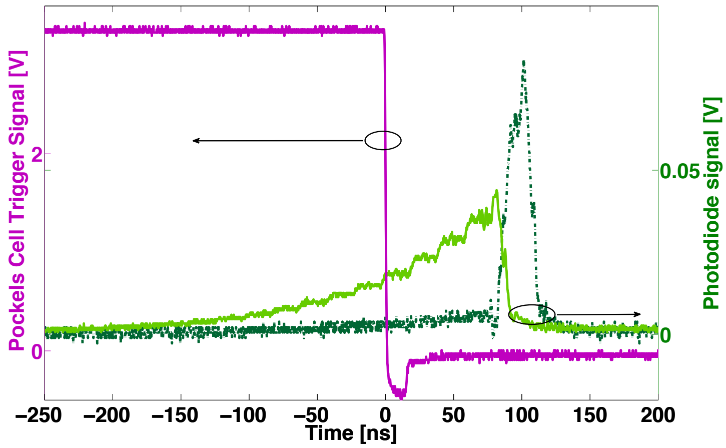

Fig.3. Cavity-dumped operation. The purple curve indicates the end of the trigger signal for the Pockels cell, whereas the green curves are the photodiode signals. The plain, light green curve corresponds to the build-up of intra-cavity laser radiation from noise, and the dotted, dark green curve corresponds to the cavity-dumped pulse.

To operate the laserhead in the cavity-dumped regime, the switching elements were incorporated in the extension of the resonator. They added around 2% losses in the cavity, leading to an output power of 16.7 W with the quarter-waveplate set to maximal output coupling. The cavity was operated cavity-dumped, unseeded, at 200 Hz and 1 kHz repetition rates. The photodiode signals shown on Fig. 3 display the last round-trips of the build-up of the intra-cavity laser radiation from noise and the switched out pulse. The build-up is still exponential, not yet showing sign of saturation, indicating the potential for extracting higher energies. The output pulse duration was 20 ns, corresponding to the 6 m cavity length. The build-up time was set to 1.51 µs at 1 kHz and 1.81 µs at 200 Hz. In both cases, we experienced a surface damage on one of the crystals for dumped energies between 2 and 3 mJ. Even though the lifetime of ytterbium ions in Lu_2O_3 host is 805 µs, no bistability was observed at 1 kHz and for the gate lengths used. The reproducible surface damage occurred thus for an intensity of only 35 MW.cm^{-2}, which is low for a bulk material. Therefore, this is probably caused by the quality of the crystal surface.

4. Conclusion

In this work, 9.9 W were extracted from a single 1.5% doped Yb:Lu_2O_3 bulk crystal and 19.5 W from the two-crystal resonator in CW regime. When cavity-dumped, for the first time to our knowledge, the energy extracted was limited to 3 mJ for 200 Hz and 1 kHz repetition rates, due to surface damage occurring at an intensity of only 35 MWcm^{-2} intensity. However, to date, this does not seem to be a fundamental limitation of the crystal, but rather a surface quality problem. With the demonstrated CW power, energies as high as 10 mJ in the cavity-dumped operation or seeded regenerative amplifier operation can be expected. Further work would consist of seeding the amplifier with an appropriate oscillator.

5. References

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