Optimized temperature/bandwidth operation of cryogenic Yb:YAG composite thin-disk laser amplifier

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Abstract: The temperature of a high energy pulsed, cryogenic Yb:YAG composite thin-disk amplifier is optimized for bandwidth to enable extraction of pulses <10 ps in duration for OPCPA pumping.

OCIS codes: (140.3280) Laser amplifiers; (140.3538) Lasers pulsed; (140.3480) Lasers, diode-pumped

1. Introduction

High energy lasers at high repetition rate are in great demand for various applications such as pumping of optical parametric chirped pulse amplifiers (OPCPA´s), material processing or in scientific instruments such as lasers used in pump-probe experiments in FEL facilities. The OPCPA systems are favored for producing the IR output to drive the high harmonic generation (HHG) or other coherent X-ray sources. For scientific applications, a high repetition rate is useful when the count-rate determines the duration of the experiment.

The heat removal of such high energy, high repetition rate laser drivers has been a challenge; the thin-disk geometry is one technique providing enhanced cooling [1]. Yb:YAG and Yb:LuAG have successfully proven their high-power ability, with up to 5 kW reported from a single thin-disk in continuous-wave operation [2]. However, at high energy, parasitic lasing limits the maximum stored energy, hence the scalability. To overcome this effect, a shaped end-cap has been suggested in Ref. 3, rejecting the amplified spontaneous emission (ASE) out of the gain medium.

Operating Yb:YAG at liquid nitrogen temperature has the fundamental advantages relative to room-temperature operation of much better thermo-optic properties and dramatically reduced thermal population of the lower laser level that have led to its excellent performance in amplifiers [4, 5]. However, the generation of short energetic pulses desired for OPCPA pumping and THz generation is limited by Yb:YAG's gain bandwidth at low temperature [6]. A compromise that maintains good thermo-optic and spectroscopic properties at increased bandwidth may be reached by raising the temperature to 130-150 K in the intermediate amplifier stage(s).

In this summary, we are reporting on the characterization of both temperature and bandwidth of a cryogenic Yb:YAG composite thin-disk laser amplifier.

2. Experimental setup and results

The laser-head was based on a multipass amplifier constituted of the composite thin-disc (CTD) and a telescope for relay-imaging the beam, ensuring a high beam quality after amplification, as demonstrated first in [7]. The setup is shown on Figure 1 with photos. In the relay-imaging telescope, a spatial filter composed of a small aperture at the focus was employed to clean up the spatial distortions. Due to the flat-top spatial distribution of the pump, the amplified beam acquired after a few passes a smooth super-gaussian beam profile. This is of advantage for later pumping of OPCPA´s. First, in order to characterize the extractable power from the CTD, the telescope for the relay imaging was removed and a multi-mode cavity, consisting of the CTD, a 300 mm focusing lens and an output coupler, was built. The available output couplers were 7.5%, 10% and 15%.

The measurement of the efficiency obtained with the different output couplers is shown on Figure 2 (left). Here, the pump laser diode was set in quasi-continuous-wave operation mode, at 10 Hz repetition rate, and the pulse duration was varied from 1 ms to 30 ms, corresponding to an average pump power from 5 W to 150 W. The crystal temperature was kept constant between 82 K and 93 K. The slope efficiency was maximum for 10% output coupling with 52.1% optical-optical efficiency. Even at the maximal pump power, the efficiency curve was still linear, indicating no limitation from thermal effects or ASE. With 150 W of pump power, the highest extracted output power was nearly 80 W with 10% output coupling and dropped to 74.8 W and 70.0 W for output coupling levels of 7.5% and 15% respectively.

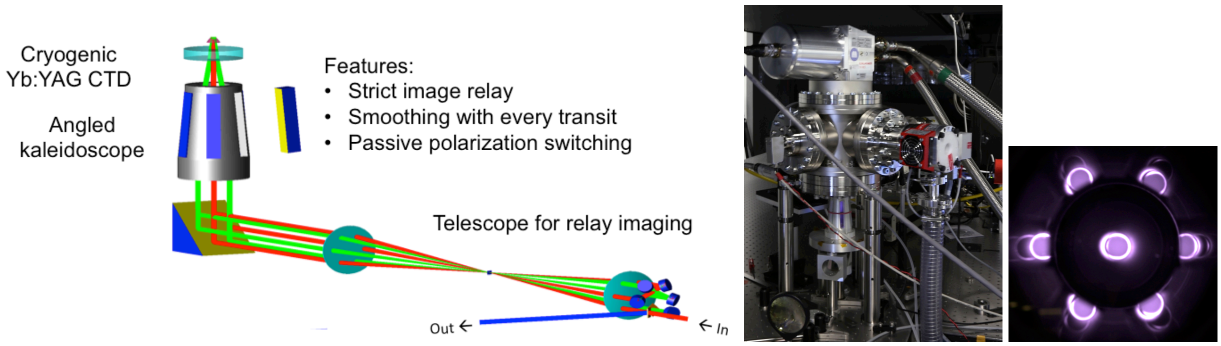

Fig. 1. Layout of the multi-pass amplifier (left), showing the cryogenic composite thin-disc, the kaleidoscope and the relay-imaging telescope with spatial filter through a pin-hole. Middle: Photo of the cooling head with the vacuum chamber. Right: Photo of the pumped thin-disc with reflections on the kaleidoscope mirrors.

On the right side of Figure 2, the dependency of the output power with the crystal temperature is shown. As expected, due to the decrease of the absorption and emission cross-sections with the temperature increase, the output power decreased from 79.9 W to 23.8 W.

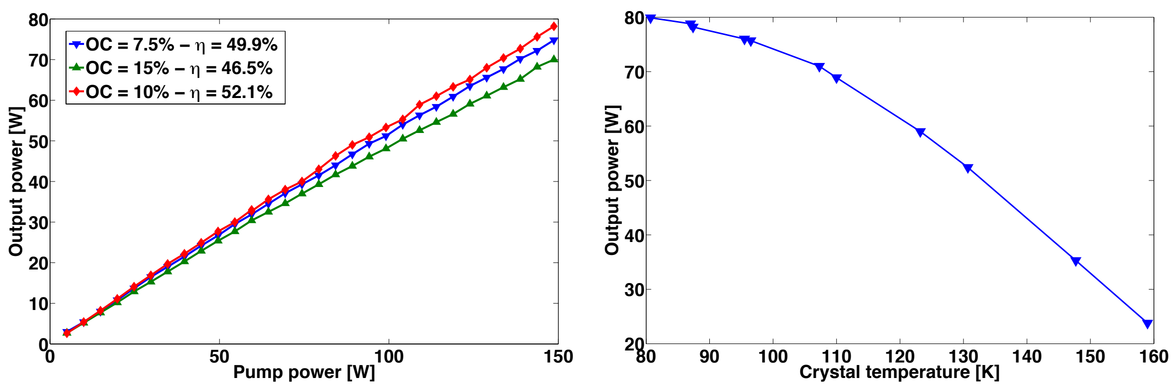

Fig. 2. Power efficiency with variation of the output coupling (left) and dependency of the output power on the crystal temperature (right).

The measurements of the spectral bandwidth were realized with the amplification of 1 mJ, 1 kHz, 1030 nm pulses out of a commercial regenerative amplifier (Amplitude System s-pulse HP2 custom) seeded with a home-made fiber oscillator. The pulses were stretched to 200 ps and their spectrum supported pulses below 500 fs. By increasing the average pump power, the population inversion in the crystal was increased, thus the gain per pass was higher. The left graph on Figure 3 displays the calculations of the available bandwidth at 77 K and 130 K, with the measured data points. The measurement was in good agreement with our calculation. The available spectral bandwidth is 0.6 nm for saturated gain at 77 K.

On the right graph, the normalized spectrum was taken for different pump powers. As a reference, the spectrum before the multipass amplifier is also shown. Above 200 W of pump power, the spectral bandwidth was narrowed down to 0.75 nm and remained constant for higher pump power. The central wavelength was 1028.9 nm independently of the pump power. The amplified spectrum supported Fourier-transform limited pulses below 2 ps. After 12 passes amplification, the energy reached 50 mJ per pulse at 100 Hz repetition rate.

At the time of this writing a Helium refrigerator fitted with a heater for the precise control of the composite disk temperature has been activated. We plan to extract pulses and collect bandwidth versus temperature data for extracted pulses that will be presented at the time of the conference.

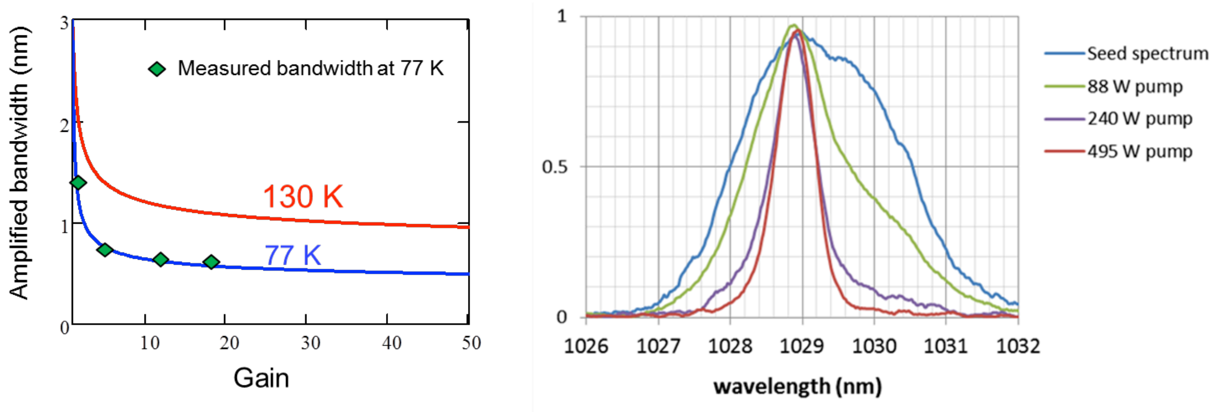

Fig. 2. Study of the influence of the temperature on the bandwidth after amplification. Left: Calculated bandwidth for 77 K and 130 K depending on the gain; the green diamond are measured data. Right: Narrowing of the amplified spectrum with the increase of the pump power.

3. Conclusion

We demonstrated the operation of the cryogenically cooled composite thin-disk by tuning the temperature and choosing the best compromise between lasing efficiency and bandwidth. The minimal bandwidth, obtained for pump power higher than 200 W and at 77 K crystal temperature, was 0.6 nm, corresponding to 1.8 ps long transform-limited pulses.

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