High power cw and fs Yb:CALGO thin-disk laser using diamond heat spreader (orale)

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Abstract: We present the study and results on high-power oscillators based on Yb:CALGO in thin-disk laser architecture using a diamond heat spreader for thermal management both in cw (spatially multimode and single-mode) and in femtosecond regime.

OCIS codes: (140.3615) Lasers, ytterbium; (140.6810) Thermal effects ;(140.4050) Mode-locked lasers

1. Yb:CALGO in the thin-disk scene

In the realm of high-power ultrafast laser, thin-disk laser (TDL) technology has a crucial interest [1]. The thermal control of the gain medium permits the generation of high average power and high-energy fs pulses directly out of an oscillator. From the past few years, some research efforts have focused on reducing the pulse duration using this technology. Yb:YAG is the most commonly used crystal in TDL oscillators, and recent results report remarkable results in terms of pulse durations with this material. 275 W of average output power with 583 fs pulse has been demonstrated [2]. Moreover, using the Kerr effect to decrease pulse duration has allowed the generation of 200 fs pulses with an output power of 17 W [3]. Another way to obtain shorter pulses consists of using crystals with broader emission bandwidths. In particular, sesquioxide crystals (Yb:$LuScO_3$, Yb:Lu_2O_3) have been used to generate short pulses, and recently allowed the generation of sub-100 fs pulses [4]. In all these experimental demonstrations, a clear trend is that the generation of shorter pulses has the consequence of a lower average power. Other crystals with even broader bandwidths –such as Yb:KYW, Yb:KLuW, Yb:YCOB– have also been used in TDL architecture to produce short pulses [5]. These crystals have shown interesting performances in terms of pulse duration. However, tungstate and borate crystals suffer from low thermal conductivities and from mechanical and structural inhomogeneity, which leads to strong beam distortion under thermal stress. This limits their use in high average power TDL. In this point of view, the properties of Yb:CALGO are quite unique thanks to its very broad and smooth emission spectrum, which make it very attractive for high-power ultrafast lasers [6-9].

In this contribution, we present the first femtosecond thin-disk oscillator using Yb:CALGO. However, we will focus in this report key aspect to achieve high average power in TDL. The limitations of the copper heat sink [10] will be explored together with the approach to overcome them by using diamond heat spreaders. An original comparative study on the thermal behavior of the Yb:CALGO-TDL mounted on diamond heat spreader (in comparison to the copper heat sink) will be discussed in order to explain the improved performances obtained in cw and in femtosecond regime [11].

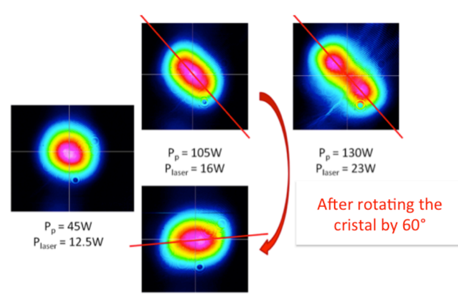

Figure 1. Thermal astigmatism observed in TDL using Yb:CALGO with a copper heat spreader.

2. Why a special heat spreader?

The experiment in the following is performed with a 2%-doped, 350-µm-thick, Yb:CALGO crystal. The crystal diameter is 6 mm, and it is cut for the laser beam to propagate along the σ-axis, with access to both σ- and πpolarization. In a first experiment, the crystal is glued on a copper heat sink and pumped at up to 200 W at 980 nm. A 24-passes pumping unit was used together with a pump spot diameter of 2.3 or 2.9 mm on the disk. In this last configuration, we could pump up to ≈ 90 W output power while keeping a good TEM_{00} beam profile. Above this power level, the beam starts to be elliptical due to thermal distortions as shown in figure 1 and becomes strongly multimode above 130 W of output power. To confirm that this distortion is associated to the crystal orientation we rotated the orientation of our crystal by 60° and we observe that the astigmatism follows the rotation of the crystal, cf. fig. 1. Furthermore, we measure the temperature of the surface of the disk versus the pump power with the copper mount (fig. 2). For a 2.3-mm pump beam diameter, the temperature-vs-pump-power slope is 0.62 K/W and for a 2.9-mm pump beam, this slope is 0.37 K/W which inversely proportional to the luminance ratio.

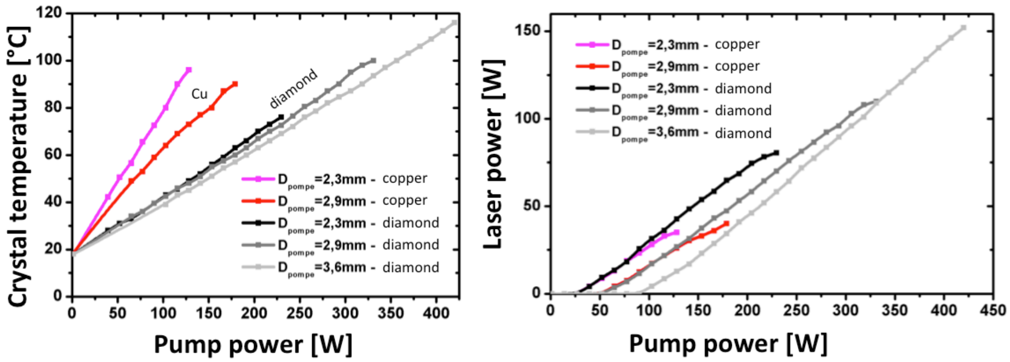

Figure 2. (Left) temperature dependency versus the pump power for various mounts and spot diameters. (Right) laser performance for various mounts and spot diameters.

3. High-power cw results

In order to increase the power, the same kind of crystal is glued on a diamond heat sink. The same temperature measurements procedure, as with the copper mount, is applied here. As can be clearly seen in figure 2, the results are quite spectacularly improved. The temperature slope versus the pump power is drastically reduced and almost does not depend on the pump beam diameter (fig. 2) over the pump power range we used in this experiment. The temperature-vs.-pump-power slope is 0.25 K/W for a 2.9-mm pump beam, and this slope slightly decreases down to 0.23 K/W for 3.6-mm pump beam diameter.

The laser power performances are clearly depending on this improvement. In fact, using a simple I-shape cavity, the laser power is measured versus the pump power (fig. 2). At low powers level, both the copper and diamond mounts lead to comparable results. However, the curves associated with the copper mount inflect at pump powers level three times lower than that obtained with the diamond mount (fig. 2-right). This is in good agreement and corresponds to the ratio observed between the slopes of temperature-versus-pump-power (fig. 2-left). The maximum laser power obtained in this multimode configuration is 152 W for a pump power of 420 W using a pump spot diameter of 3.6mm. At this maximum output power, the temperature elevation was measured to be 100 K. It is worth mentioning that at this latter pump spot size no roll over are observed even at full power.

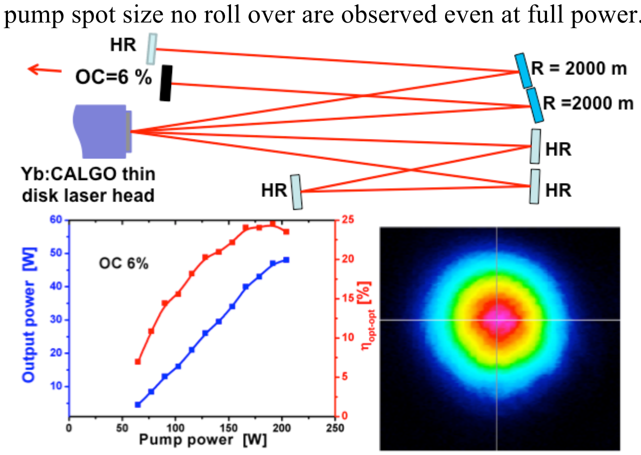

Figure 3. (Top) cavity to operate in high-power spatially single-mode laser. (Bottom) corresponding output power and beam profile.

In order to operate in TEM_{00} laser mode, a more complex cavity is built (fig. 3). The pump beam diameter is reduced to 2.9 mm. In these conditions, we demonstrate a cw power of 50 W with 25 % of optical-optical efficiency.

4. High power femtosecond results

Inserting in this cavity a 0.5 %-modulation-depth SESAM (from BATOP GmbH) with a saturation fluence of 90 $\mu J/cm^2$ and -2000 fs2 GTI mirrors, up to 28 W of average power has been obtained in femtosecond regime. The pulse duration is then 300 fs corresponding to pulse energy of 1.3 µJ for a repetition rate of 23 MHz. In order to reduce the pulse duration a fused silica plate (3-mm-thick) is inserted in the cavity (fig. 4-left) to add Kerr self-phase modulation. In this configuration, 20 W of average power has been extracted with pulse duration of 197 fs corresponding to an energy of 0.9 µJ. The autocorrelation and spectral traces are shown in fig. 4-right.

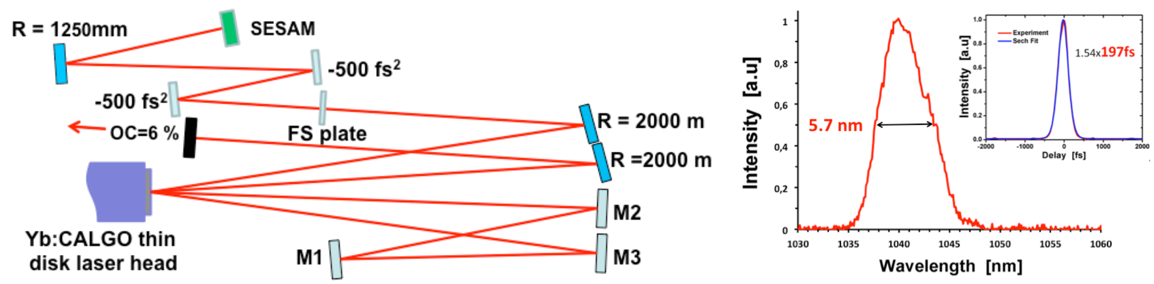

Figure 4. (Left) Cavity for high-power fs laser. (Right) Spectrum and autocorrelation of 197 fs pulses at 20 W.

5. Conclusion

We demonstrated qualitatively and quantitatively the importance of the diamond heat spreader in order to obtain high power TDL operation using Yb:CALGO. First, in cw-operation, an output power of 150 W in spatially multimode operation and 50 W in fundamental mode (TEM_{00}) has been demonstrated. Furthermore, in femtosecond regime, up to 28 W output power has been achieved with 300 fs pulses.

6. Acknowledgements

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7. References

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